CONCEPTUAL FRAMEWORK FOR ENVIRONMENTAL RATING SYSTEMS FOR INFRASTRUCTURE PROJECTS IN SRI LANKA: APPLICATION TO SMALL HYDROPOWER PROJECTS

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DECLARATION

I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

Thilini Shiromani Jayawickrama

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SUMMARY

Along with the increased awareness of environmental impacts of construction, the demand for sustainable construction has also been growing with an increasing international movement. It is this movement that has given rise to the development and usage of environmental assessment methods which provide a systematic approach to the evaluation of the environmental performance of construction projects and constructed items. Environmental rating systems (ERSs) were developed to address a wide range of environmental impacts of buildings and infrastructure. ERSs provide objective and comprehensive means of simultaneously assessing a broad range of environmental considerations against explicitly declared criteria, and offer a summary of overall performance.

Though infrastructure development is important for a country's socio-economic structure, there is also a dark side to infrastructure development due to their environmental impacts. It is important to consider these consequences, especially in developing countries, which are experiencing an increasing demand for infrastructure. However, several researchers have stated that ERSs published so far have tended to focus more on buildings, paying less attention to infrastructure. Only a few systems exist for infrastructure assessment. Moreover, existing ERSs have not escaped criticism. Several researchers have pointed out a major deficiency in ERSs by noting the absence of an agreed upon theoretical basis for ERSs. Theory lags behind practice in this field. Motivated by these gaps, the present study aimed to develop a theoretical basis for ERSs for assessing infrastructure projects in Sri Lanka.

The literature review highlighted an emerging trend to take into consideration a wide range of sustainability aspects in ERSs, but showed that there is little agreement on which view of sustainability to be followed. The study reviewed the theoretical underpinnings of environmental sustainability in infrastructure development as the basis for assessing infrastructure projects. Literature review identified that, given the actual physical limitations imposed by the natural environment on economic activities, the natural environment should be

sustained for everything else to be sustained. However, since some socio-economic issues become barriers to environmental sustainability in developing countries, these issues should be minimised to increase attention to the environmental issues in the region. Review of literature identified eight major factors and the sub-factors under these as important in reaching environmental sustainability in infrastructure projects in developing countries after which the hypothesis was presented.

In order to propose the conceptual framework, these factors were analysed for their severity/importance in infrastructure development. Although the importance of absolute measures to determine the carrying capacity of the environment is identified, such measures are still not sufficiently available and hence the study has to depend on expert opinion. A questionnaire survey was conducted with experts in the infrastructure sector. An approach identified in the literature review was used to develop the conceptual framework that break down the environmental problems and solutions into several detailed levels. Analytic Hierarchy Process (AHP) was selected to analyse survey data. Interviews were carried out with experts in the infrastructure sector for in-depth explorations of the survey responses in order to supplement the survey results. The study was carried out in Sri Lanka, a developing country which is experiencing a rapid growth in infrastructure development. The factor "Biodiversity" received the highest score among eight main factors considered. The factor addressing "Waste" issues and issues related to "Usage of Non-renewable Energy Sources" received the second and third highest scores respectively.

The proposed conceptual framework was validated and applied to the small hydropower (SHP) sector in order to demonstrate how to develop type-specific ERSs for infrastructure projects in Sri Lanka. The validation exercise was conducted with the purpose of seeking expert opinion on the proposed conceptual framework for ERSs for assessing infrastructure projects in Sri Lanka. Experts strongly agreed on the factors, which address direct ecological impacts. They found the implementation framework to be generally acceptable. They also found the comprehensiveness and life-cycle coverage of the conceptual framework. They pointed out that the method adopted in the present study of breaking down the problems into several levels in addressing the issues is useful because it enables the modifications of the weightings according to the relative importance of factors at any given point in time with the changing nature of developmental activities. Hence, the conceptual framework provides the basis for developing type-specific, region-specific and up-to-date ERSs for infrastructure projects.

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LIST OF ABBREVIATIONS

ACE	Association for Consulting and Engineering
ADB	Asian Development Bank
ADBI	Asian Development Bank Institute
AHP	Analytic Hierarchy Process
BASIX	Building Sustainability Index
BCA	Building and Construction Authority
BEPAC	Building Environmental Performance Assessment Criteria
BERDE	Building For Ecologically Responsive Design Excellence
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System Built Environment Efficiency
CEA	Central Environmental Authority
CEB	Ceylon Electricity Board
CECA	Civil Engineering Contractors' Association
CEEQUAL	Civil Engineering Environmental Quality Assessment and Awards Scheme
CFCs	chlorofluorocarbons
CIB	International Council for Building Research Studies
CSC	Certificate of Statutory Completion
DEFRA	Department for Environment, Food and Rural Affairs
DEL	Department for Employment and Learning
DfE	Department for Education
DGNB	German Sustainability Building Council
DOE	Department of Energy

ECG	Evaluation Coordination Group of the international financial institutions
EIA	Environmental Impact Assessment
EMAS	Eco-Management and Audit Scheme
ERSs	Environmental rating systems
ESGB	Evaluation Standard for Green Building
FAO	Food and Agriculture Organization of the United Nations
FSC	Forest Stewardship Council
GBC	Green Building Challenge
GBCA	Green Building Council, Australia
GBCSL	Green Building Council Rating System in Sri Lanka
GBI	Green Building Index
GDP	Gross Domestic Product
GHG	greenhouse gases
GLASOD	Global Assessment of Soil Degradation
GLS	Government Land Sales
GOSL	Government of Sri Lanka
GRIHA	Green Rating for Integrated Habitat Assessment
GSA	General Services Administration
GW	gigawatt
HCFCs	hydro-chlorofluorocarbons
HK BEAM	Hong Kong Building Environmental Assessment Method
ICE	Institution of Civil Engineers
IEE	Initial Environmental Examination
ISCA	Infrastructure Sustainability Council of Australia

ISO	International Organisation for Standardisation
ISSS	International Society of Soil Science
KGBC	Korea Green Building Council
KWh	kilowatt-hour
LCA	life cycle assessment
LEED	Leadership in Energy and Environmental Design
MASL	Mahaweli Authority of Sri Lanka
MDGs	Millennium Development Goals
MGI	McKinsey Global Institute
MNRE	Ministry of New Renewable Energy
MW	megawatt
NatHERS	Nationwide House Energy Rating Scheme
NRE	Non-renewable Energy
OECD	Organisation for Economic Co-operation and Development
PWGSC	Public Works and Government Services Canada
SBC	Sustainable Building Challenge
SBTool	Sustainable Building Tool
SEA	Strategic Environmental Assessment
SHP	small hydropower
SGBC	Singapore Green Building Council
SPPA	Standardized Power Purchase Agreements
TOP	temporary occupation permit
UNCED	United Nations Conference on Environment and Development
UNCSD	United Nations Conference on Sustainable Development
UNEP	United Nations Environment Programme

URA	Urban Redevelopment Authority
VSS	Very Strong Sustainability
VWS	Very Weak Sustainability
WCED	World Commission on Environment and Development
WELS	Water Efficiency Labelling and Standards
WGBC	World Green Building Council
WSSD	World Summit on Sustainable Development

Chapter 1: Introduction

1.1. Background

The fallouts of unsustainable economic and social activities which have a major impact on the environment are too evident today. The examples of such fallouts include climate change, ozone layer depletion, pollution, resource depletion, food shortages and health problems. The natural environment provides the base for almost all economic activities and there is evidence that the increasing economic and development activities that are incompatible with the carrying capacity of this supporting natural environment cause many of the environmental problems identified above. Sustainable development has gained in popularity over time as a way to address these problems.

The construction industry has long been identified as causing environmental problems, ranging from the excessive consumption of global resources during construction and operation to the pollution of the surrounding environment (Ding, 2008). For example, it is estimated that buildings are responsible for the consumption of 40% of the world's energy, 25% of the global water, and 40% of the planet's raw materials, and that this not only contributes to resource depletion but to the emission of one third of global greenhouse gases (GHG) (UNEP, 2013).

The construction industry has begun to recognize the adverse environmental impacts of their activities since the 1990s (Haapio and Viitaniemi, 2008). Along with the increased awareness of environmental problems, the demand for sustainable construction has also been growing (Abdalla et al., 2011) with an international movement for sustainable construction (Mateus and Braganca, 2011). It is this movement that has given rise to the development and usage of environmental assessment methods which provide a systematic approach to attaining the goals of sustainable construction (Mateus and Braganca, 2011; Wallhagen and Glaumann, 2011). These assessment methods can deliver environmental guidelines, benchmarks, and ratings and, by evaluating and measuring environmental performance, they may form the basis of incentives and regulations to minimize the environmental impacts of construction projects and constructed items (Wallhagen and Glaumann, 2011).

In the last two decades, interest has grown in the environmental assessment of buildings (Forsberg and von Malmborg, 2004; Todd et al., 2013), leading, in turn, to the emergence and increased involvement of accreditation bodies, both commercial and government, and research organizations in the introduction of third party certifications to assess and promote environmental performance in the sector (Glavinich, 2008; Abdalla et al., 2011). These certifications, among which are Environmental Rating Systems (ERSs), play an important role in managing green construction projects (Kajikawa et al., 2011). They assemble a wide range of environmental issues and weight the performance of projects in relation to these issues and aggregate them into overall judgements (Wallhagen and Glaumann, 2011).

There has been a proliferation of ERSs around the world since the launch of the Building Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom in 1990 (Abdalla et al., 2011; Todd et al., 2013). Haapio and Viitaniemi (2008) noted that ERSs have gained in recognition and that they are widely applied in the sector. For example, while BREEAM schemes have been used since 1990 to certify 15,000 projects, the Green Mark Scheme of Singapore's Building and Construction Authority (BCA) has been applied to certify more than 1,000 building projects since 2005. ERSs have gained widespread attention in developing countries as well. Green Rating for Integrated Habitat Assessment (GRIHA) in India which has been used to certify 425 projects since 2008 (GRIHA, 2013) and Green Building Index (GBI) in Malaysia which has been applied for the certification of over 75 million square feet of buildings since 2009 (Green Building Index, 2013) are some of the examples. Moreover, a number of ERSs have been recognized by the public authorities in several countries such as Australia, China, Hong Kong, Japan, UK and USA (Cole, 2005; Poston et al., 2010; Schweber, 2013; Lee, 2013). As emphasized by Wallhagen and Glaumann (2011), the importance and influence of ERSs will continue to increase and therefore, it is important to further examine them.

Infrastructure items play a vital role in the economic and social development of a country because they form the basis of much modern-day economic activities. Infrastructure constitutes a major economic sector in its own right and contributes to raising the living standards and the quality of life of people in the modern world (OECD, 2006). The services provided by infrastructure range from those that satisfy basic human needs to those addressing the requirements of large-scale industries including energy and utilities (electricity and gas), transportation (road, railways and bridges), water supply and sanitation services and telecommunication systems (Palliyaguru et al., 2007).

The World Bank (2013a) has identified infrastructure development as a catalyst in addressing many of the systemic development challenges of today's world, seeing infrastructure development as critical for social progress and the attainment of the Millennium Development Goals (MDGs), a set of international development goals that were agreed upon by the leaders of member countries of the United Nations in 2000 with 2015 as the target year (United Nations, 2013).

The McKinsey Global Institute (MGI, 2013) has estimated that $57 trillion of investments is required for infrastructure between 2013 and 2030 simply to maintain projected global gross domestic product (GDP) growth. MGI (2013) has moreover shown that this is nearly 60% more than the $36 trillion spent globally on infrastructure over the past 18 years. According to Bhattacharya et al. (2012), there is a well-documented infrastructure deficit globally since an estimated 1.4 billion people still have no access to electricity, 0.9 billion are without access to safe drinking water, and 2.6 billion are without access to basic sanitation.

As MGI (2013) has pointed out, though the global growth poles are centred in the developing world, high growth rates in emerging markets are being constrained by the inadequacy of infrastructure quality and quantity in this region. Hence, driven by the pace of urbanization and the development plans of these countries, there is a growing demand for more and better infrastructure in the developing world.

The Organisation for Economic Co-operation and Development (OECD) (2006) has shown that nearly half of the international financial institutions' lending to developing countries goes to infrastructure. The OECD has further estimated the likely investment in these countries for infrastructure to be $700 billion a year in the coming decade, rising to $1 trillion a year by 2030 (OECD, 2006). The World Bank (2013a) has shown that access to basic infrastructure services remains an issue in both low-income countries as well as in many middle-income countries where the demand for infrastructure is outstripping current investment levels with a gap estimated at $ 1 trillion. They predict that this demand will continue to grow as countries develop. According to the estimates by the Asian Development Bank (ADB) (ADB and ADBI, 2009), approximately $ 8 trillion will be spent on infrastructure from 2010 to 2020 in Asia alone. These future investments in infrastructure are expected to contribute to an increase in productivity and future economic growth in developing countries where the quality of the infrastructure is far from satisfactory (Kim, 2006).

Like many other developing countries, Sri Lanka has registered an increase in demand for infrastructure development. This demand has further increased due to post-war reconstruction efforts after the 30-year civil war as well as the projected increase in developmental trends arising from the long-term development plans of the current government as articulated in the presidential election manifesto titled *"Mahinda Chinthanaya"* (Department of National Planning, 2010). An ambitious program of infrastructure development by the Sri Lankan government to completely upgrade the transportation, power and telecommunication sectors of the country has triggered a massive infrastructure development drive (BOI, 2013).

However, there is a dark side to infrastructure development. It has significant impacts on the natural environment (ECG, 2007). Almost all infrastructure projects involve large scale construction activities and, hence, utilize large land areas and many resources as well as having long operational periods, thus exerting significant impacts on the natural environment. It is therefore important to strike a balance between meeting the goals of providing infrastructure requirements and reducing their adverse environmental impacts (ECG, 2007; Ugwu and Haupt, 2007). The Evaluation Coordination Group (ECG) of the international financial institutions has underlined the need to pay more attention towards environmental issues throughout the whole project life of infrastructure development.

According to ECG (2007), consideration should be given not only to reducing adverse environmental impacts but also to improving the environment through long-term strategies in infrastructure development that aim at environmental sustainability. For example, investment in urban mass transit systems can be more environment-friendly than investment in extensive road systems that encourage automobile use, extended urban development, and the concomitant rise in demand for fuel (ECG, 2007). Similarly, dam projects for power generation and/or irrigation carry the indirect benefit of flood control downstream. In Sri Lanka, the demarcation and declaration of forest reserves under reservoir projects have simultaneously created large habitats for the country's fauna and flora species. Likewise, while infrastructure projects often require mitigation measures to minimize the damage to the environment, in some cases, they have directly reduced the need for mitigation and enhanced environmental benefits (ECG, 2007). Thus it is necessary to design, construct and operate infrastructure projects in such a way as to mitigate adverse environmental impacts and to enhance environmental quality or benefits where possible. ERSs, as has happened in the case of the building sector, can be used in the infrastructure development sector as well in order to attain these goals.

ERSs play an important role in sustainable development. It is therefore timely and worthwhile to undertake a study of ERSs for assessing infrastructure projects taking into consideration current growth in infrastructure development in developing countries. Sri Lanka is the particular focus in this study.

1.2. Knowledge Gap and Research Question

Several researchers have stated that ERSs published so far have tended to focus more on buildings, paying less attention to infrastructure assessment

(Glavinich, 2008; Ugwu and Haupt, 2007; Wong, 2010). A review of the literature also indicates that though many ERSs for assessing buildings are being used in both developed and developing countries, only a few systems exist for infrastructure assessment. The above highlights a critical gap in the existing assessment systems many of which do not cover items of infrastructure.

However, in spite of the popularity and wide application of existing ERSs, many researchers have identified a range of shortcomings in them (Cole, 1998; Kajikawa et al., 2011; Alyami and Rezgui, 2012). Issues in the selection of criteria and weighting systems and deficiencies in real life application are some of the criticisms. Cole (1998) and Retzlaff (2009) have pointed out a major deficiency in ERSs by noting that there is no agreed upon theoretical basis for the inclusion of criteria and weighting factors. Brandon and Lombardi (2011) also have pointed out the absence of an agreed upon theoretical framework for environmental assessment despite the number of methods currently in use. Therefore, theory lags behind practice in this field which also leads to many of the shortcomings of ERSs. A majority of ERSs have been developed as part of market-based mechanisms. Although there are a few ERSs based on academic research, studies examining the theoretical basis for ERSs are not available to date. For example, Ali and Al Nsairat (2009) developed a green building rating system for residential units in Jordan by studying existing international ERSs to define assessment items and included some new assessment items taking into consideration local conditions and weighting for regional adaptation. Banani (2011) adopted a similar approach when developing a sustainable assessment method for non-residential buildings in Saudi Arabia. What is lacking in these studies is the theoretical underpinning for the selection of the specific criteria.

With increasing awareness of the environmental impacts of construction, professionals in the construction industry face the challenge of translating strategic sustainability objectives into concrete action (Ugwu and Haupt, 2007). ERSs provide one approach to addressing this challenge and it requires translating broad sustainability goals into project level actions. Research in sustainability can contribute to addressing these challenges (Ugwu and Haupt, 2007).

It is therefore important to re-examine the current needs with regard to sustainability in the sector and to establish a theoretical basis for ERSs which support the attainment of the goals of sustainability.

Motivated by the existence of these gaps, the present study addresses the following research question: “How to determine a theoretical basis for ERSs for infrastructure projects in Sri Lanka?”

1.3. Aim and Objectives

In line with the research question, the aim of the study was to develop a theoretical basis for ERSs for infrastructure projects in Sri Lanka based on the concept of environmental sustainability.

Therefore, the specific objectives of the study were to:

- identify the theoretical underpinnings of environmental sustainability in infrastructure development as the basis for assessing infrastructure projects;
- propose a conceptual framework for developing ERSs in the Sri Lankan infrastructure sector; and,
- apply the proposed conceptual framework to a specific infrastructure project type in Sri Lanka in order to demonstrate how to develop theoretically sound type-specific ERSs.

1.4. Scope

<u>Unit of Analysis</u>

The study focused on infrastructure projects and analysed their environmental sustainability.

Unit of Observation

Data collection on the environmental sustainability of infrastructure projects was carried out among experts who undertake environment-related work on such projects.

Geographical Coverage

The study was carried out in Sri Lanka, a developing country which is experiencing rapid growth in infrastructure development after the end to the 30-year civil war and pursuant to the specific vision for development of the present government which prioritizes infrastructure development in its calls for a growth rate of 8% (Biller and Nabi, 2013). These factors make carrying out this study for the Sri Lankan infrastructure sector timely.

Selection of the Infrastructure Type for the Study

The power generation sector is vital for a country's socio-economic and livelihood development since both human activity and industry depend on the energy supply. In the case of Sri Lanka, there is a significant increase in demand for electricity and this demand outstrips the supply level of electricity at the moment (Ferdinando and Gunawardana, 2011). The country's power generation, moreover, is currently in transition from a hydropower-dominated mix to a thermal-power-dominated one which carries environmental as well as economic drawbacks. Therefore, the government is continuing to take measures to increase investments in non-conventional renewable energy sources such as small hydropower (SHP), wind power, biomass power and solar power. Of these, the government has promoted SHP generation in order to get the maximum out of the hydropower potential in the country (Rupasinghe and de Silva, 2007). Consequently, the SHP sector has shown considerable growth in Sri Lanka. In recent times, the SHP sector has garnered interest in many other countries with good hydropower potential such as China, India, Nepal, Vietnam and many South American countries (Hennig et al., 2013; Kumar and Verma, 2007; Budhathoki, 2011).

However, while these projects were earlier operated and managed by village-level societies where both the beneficiaries and those impacted were of the same community (Thoradeniya et al., 2007), at present, some of the beneficiaries are those from the private sector for whom such projects are commercial ventures connected to the national grid. As a result, some of the environmental and social impacts of such ventures receive less attention (Thoradeniya et al., 2007). The SHP sector shares the largest percentage of the non-conventional renewable energy sources in the country. In 2012, non-conventional renewable energy sources accounted for 9% of the total installed capacity in the country of which 72% came from SHP plants, which also accounted for 6.8% of the total installed capacity in the country (CEB, 2012).

Since SHP generation is both on the rise and not without environmental problems (Abbasi and Abbasi, 2011), the present study selected the SHP sector in order to illustrate the application of the proposed conceptual framework for ERSs in the study.

1.5. Method of Research

A cross-sectional survey design was selected for this study. The target population consisted of experts in the infrastructure sector while a combination of purposive and snowball sampling methods was used which are a non-probability sampling methods (Tan, 2008). The sample consisted of Sri Lankan ecologists, environmental economists, Environmental Impact Assessment (EIA) experts and academics. Structured questionnaires were used to collect data on the importance of the factors in the proposed framework. The data were then analyzed using the Analytical Hierarchy Process (AHP) technique. The framework was applied to the Sri Lankan SHP sector which is the selected infrastructure project type. Field visits to and interviews with members of the public living in the vicinities of SHP projects, referrals of EIA and Initial Environmental Examination (IEE) reports of SHP projects, and interviews with experts in the SHP sector were used to identify both the adverse and positive impacts of Sri Lankan SHP projects.

1.6. Significance of the Research

This research addresses the absence of a theoretical basis for ERSs and the dearth of studies on ERSs for assessing infrastructure projects. As there are no studies so far to establish a theoretical basis for ERSs, the present study will contribute to improving ERSs by adapting concepts of Environmental Economics and the broad objectives of sustainable development into project level actions.

Infrastructure items are important for a country's socio-economic development and there is a growing demand for infrastructure, especially in developing countries, though they cause a range of adverse environmental impacts. This makes the environmental assessment of infrastructure projects a noteworthy undertaking. It also makes it necessary to address the lack of ERSs for the infrastructure sector and study the environmental sustainability of infrastructure projects.

Sri Lanka makes a good case for undertaking this study because of the rapid growth in the demand for and development in infrastructure currently. The lessons drawn from the projects completed can be of use to projects that will be undertaken in the future in Sri Lanka as well as in other developing countries with appropriate necessary adaptations to suit the particular local contexts.

1.7. Structure of the Thesis

Chapter 1 introduces the study by outlining the background, knowledge gap and the research problem. It then presents the aim and corresponding research objectives of the study. Next, the scope of research is highlighted following by the research method, significance of the research and structure of the thesis.

Chapter 2 reviews the environmental impacts of construction and the increased global awareness of these problems. It also shows the demand for sustainable construction as a response to the international movement towards sustainable development. The chapter also discusses the different environmental assessment methods that have been developed to support sustainable construction. ERSs, which are examples of such assessment methods, form the focus of this study.

Chapter 3 reviews the literature on ERSs published in the construction sector. It also discusses the shortcomings of existing ERSs. This chapter presents the specific research gap addressed in the study.

Chapter 4 discusses the environmental problems associated with infrastructure development and the current initiatives for environmental assessments of infrastructure development. It reviews and compares the existing ERSs in the infrastructure sector.

Chapter 5 presents the scope of the study. It provides some background information on Sri Lanka, its present economic growth and the power sector. The chapter traces the evolution of the country's power sector and the increasing interest in SHP generation. Since the SHP projects have been selected for the application of the proposed conceptual framework, the chapter gives an overview of the SHP sector as well.

In Chapter 6, the conceptual framework is established and the hypothesis is presented. The chapter reviews the concept of sustainable development and the different views on environmental sustainability in order to determine the factors that should be included in the theoretical basis for ERSs. The chapter explains the concept of environmental sustainability based on the concepts of Environmental Economics.

Chapter 7 discusses the research design and methodology including sampling, data collection and data analysis technique. It gives an overview of the AHP technique, which is the data analysis technique selected for this study.

Chapters 8 and 9 present the data analysis and results, including findings from the interviews and other observations. Chapter 8 presents the results of the analysis of the factors that are identified in the conceptual framework for ERSs which are general to all infrastructure projects and validates the proposed conceptual framework.

Chapter 9 presents the results of the analysis of factors specific to the SHP sector and the application of the conceptual framework to the specific sector.

Chapter 10 discusses the main findings. It offers a comparison between the proposed framework and existing infrastructure-related ERSs.

Chapter 11 revisits the objectives of the study and discusses the degree to which they are achieved. The chapter then discusses the implications of the study, both from a theoretical perspective and from the point of view of practice. It then presents the limitations and recommendations including possible directions for future research and concludes the thesis.

1.8. Summary

The present chapter gave the background to the study which focuses on ERSs in construction. The research question was formulated based on the knowledge gaps identified. It outlined the aim and objectives of the study in relation to the research question as well as the scope and method of the study. The chapter also underlined the significance of the study in terms of the theory and practice of the relevant field. The next chapter reviews the environmental impacts of construction and the growing awareness of such impacts that gave rise to the international movement towards sustainable construction and environmental assessment in construction.

Chapter 2: Sustainable Construction and Environmental Assessment

2.1. Introduction

This chapter reviews the environmental impacts of construction projects and constructed items throughout their life cycles from material extraction, through construction, and operation to demolition. It also traces the movement towards and demand for sustainable construction. The chapter moreover describes various environmental assessment methods in construction that evaluate the environmental performance of construction projects and constructed items in the attainment of sustainability goals.

2.2. Environmental Impacts of Construction

The construction industry is one of the biggest industries in the world, facilitating human well-being and comfort by producing houses, roads, power plants and other infrastructure on which modern human society depends (Pearce et al., 2012). The construction industry accounts for around one-tenth of the GDP worldwide and construction projects are considered to play an important role in the improvement of social welfare and the quality of life (Pearce et al., 2012).

Brandon and Lombardi (2011) showed that most constructed items have negative impacts on the environment throughout their life spans, including construction, operation, maintenance and demolition. These impacts are connected with the broader problems and issues affecting the environment such as global warming, climate change, ozone layer depletion, soil erosion, desertification, deforestation, eutrophication, acidification, loss of diversity, land pollution, water pollution, air pollution, depletion of fisheries, and consumption of valuable resources such as fossil fuels, minerals and gravels (Kibert, 2008; Pearce et al., 2012).

Construction is a major strand of development that uses raw materials, some of which are non-renewable (Brandon and Lombardi, 2011). According to data from the World Watch Institute, the construction of buildings annually consumes 40% of the stone, sand and gravel and 25% of the timber in the world (Yan et al., 2010). The consumption of materials not only depletes the planet's physical resources but also requires considerable amounts of energy for their processing that ranges from extraction to manufacturing that then becomes embodied in the materials and products (Pearce et al., 2012). The manufacturing of building materials consumes about 10% of the global energy supply (UNEP, 2011, p.341). A great amount of energy is consumed by constructed items throughout their life cycles that includes the energy required for: the manufacture of building materials ('embedded' or 'embodied' energy); the transport of these materials from production plants to building sites ('grey' energy); the construction of buildings ('induced' energy); the operation of buildings ("operational" energy); and the demolition and recycling of their parts, where this occurs (Pearce et al., 2012).

Buildings are responsible for more than 40% of the energy used worldwide (Pearce et al., 2012, p.3). In the OECD countries, buildings account for around 25 to 40% of total energy consumption (OECD, 2003, p.20). Brandon and Lombardi (2011) showed that, according to McGraw-Hill Construction statistics, energy use by commercial and residential buildings, in the year 2008, varied from 20% to 56% of total energy use around the world. Increase in the use of energy increases the demand for more energy sources which mostly comes from non-renewable sources (Brandon and Lombardi, 2011).

Many scientists show that GHG emissions are closely related to global warming and climate change which result in rising sea levels, increased occurrence of severe weather events, and food shortages (Pearce et al., 2012). Yan et al. (2010) summarized the findings of thirteen studies on the sources of GHG emissions during the construction stage of buildings and showed these sources to include the manufacturing of construction materials, transportation of materials, transportation of construction equipment, energy consumption in the operation of construction equipment, transportation of workers, and the disposal of construction waste.

Furthermore, though buildings account for one third of global GHG emissions due mainly to energy consumption, there are other major emissions too, among them, chlorofluorocarbons (CFCs) and hydro-chlorofluorocarbons (HCFCs) which are used in cooling, refrigeration, and fire suppression, and halo carbons which is used in insulation materials (Pearce et al., 2012). In addition, the relatively high levels of pollutants emitted from construction materials and components can pose various health problems (OECD, 2008).

Construction activities produce a significant amount of solid waste during the production, transportation and use of materials to construct buildings (Pearce et al., 2012) as well as in the demolition of structures (OECD, 2003). The generation of solid waste in construction is estimated at 40% of the total volume of solid waste streams in developed countries, with most waste associated with the demolition phase (UNEP, 2011).

Moreover, constructed items physically disrupt the surrounding environment throughout their life cycles (Graham, 2003) since the buildings, roads, and other infrastructure contribute to the loss of soil and agricultural land in several ways (Spence and Mulligan, 1995). For example, agricultural land is lost through the activities of quarrying and mining for construction of raw materials which are utilized for the construction of physical assets; and land may also be degraded as a result of the local pollution or waste generation associated with construction and the production of building materials (Spence and Mulligan, 1995). Langford et al. (1999) showed that about 7% of the world's croplands were lost between 1980 and 1990 and Pearce et al. (2012, p.6) stated that this is mainly due to construction activities.

Construction similarly contributes to the loss of forests due to the unsustainable use of timber, in providing energy for the manufacture of building materials (Ding, 2004) and in extracting other raw materials for construction. Shah (2007) showed that 10 million hectares of forests are being cleared and destroyed every year. In addition to these direct effects, construction and building materials production activities indirectly contribute to atmospheric and water pollution (Spence and Mulligan, 1995). By reducing and destroying agricultural land and forests, construction affects biodiversity and global crop production (Pearce et al., 2012). Deforestation moreover defeats the capability of forests to sequester carbon dioxide (Kibert, 2008) and the photosynthesis which purifies the air (Pearce et al., 2012). Likewise, construction activities contribute to global warming through deforestation and the increase in burning of fossil fuels which in turn increases carbon dioxide emissions. These processes can exacerbate a greater threat facing humanity today: climate change. According to Pearce et al. (2012), no sector of the economy contributes to climate change as much as construction.

Taking into consideration the increasing awareness globally of the environmental and health issues associated with construction activities, there is a need for the construction industry to consider implementing the concept of sustainability for the purpose of reducing or mitigating those impacts (Pearce et al., 2012).

2.3. Sustainable Construction

The concept of sustainability has gained momentum over the last 20 years, the proponents of the concept having as their goal the enabling of all people to meet their basic needs and to improve their quality of life while ensuring that the natural systems, resources and diversity upon which they depend are maintained and enhanced, for both their benefit and well-being as well as for those of future generations (Pearce et al., 2012). With increasing environmental problems and global awareness regarding their consequences, the concept of sustainable development has come into use becoming one of the key research and policy issues in the early years of the twenty-first century (Brandon and Lombardi, 2011). Chapter 6 discusses the definition of the term and the theoretical underpinnings of the concept in detail. According to Hendriks (2001), though environmental problems were reported in ancient times too as evident from environmental measures taken in the Greek and Rome eras, the scale of development and the exponential growth in environmental problems have received a great deal of international attention during the second half of the 20th century. Several momentous events ensured this attention.

These events included the publications of various reports by the Club of Rome (including “Limits to Growth”); the United Nations' Conference on the Human Environment in Stockholm in 1972 resulting in the “Stockholm Declaration”; the World Commission on Environment and Development (WCED) (Brundtland Commission) in 1987 and the publication of the report “Our Common Future”; and the United Nations Conference on Environment and Development (UNCED), (Earth Summit -1992) in Rio de Janeiro declaring “Agenda 21”.

Such movement towards sustainability within the construction industry are called sustainable construction (Graham, 2003). The construction industry has a growing interest in the concept of sustainability because of the significant impacts it has on ecological and human health (Pearce et al., 2012). Kibert (2005) described sustainable construction as a subset of sustainable development that addresses the role of the construction industry in contributing to sustainability.

The first international conference on sustainable construction by the International Council for Research and Innovation in Building and Construction (CIB) was held in Tampa, Florida in 1994, at which the goals of sustainable construction were defined as “creating and operating a healthy built environment based on resource efficiency and ecological design” (Kibert, 1994). The demand for sustainable construction has been increasing strongly due to the pressure of environmental problems in construction which have posed great challenges to the construction industry (Abdalla et al., 2011). Gardner (1989) and Graham (2008) noted that sustainable construction is a process/journey rather than a future state/destination. Sustainable construction has a focus on reducing or eliminating environmental problems and issues associated with construction activities and constructed items while maximizing the potential benefits of such activities and items to the society and economy (Pearce et al., 2012).

The focus on global environmental issues and sustainable development continues to this day and several notable events have come about on account of this interest such as the World Summit on Sustainable Development (WSSD) (Earth Summit – 2002) at Johannesburg which marked Rio+10 and the resulting "Johannesburg Declaration"; and the recent United Nations Conference on Sustainable Development (UNCSD) (Earth Summit – 2012), which was held again in Rio de Janeiro, marking Rio+20 and resulting in the report "The Future We Want".

2.4. Environmental Assessment in Construction

In response to the demand for sustainable construction, the need for well-understood planning and design processes has also increased though they are activities which are complicated and require specialized teams working together in a well-coordinated and integrated way (Abdalla et al., 2011). In the movement towards sustainable construction, there was therefore a need of a yardstick to measure environmental performance (Crawley and Aho, 1999). Environmental assessment methods are the outcome of this attempt to come up with the means to assess and facilitate complicated planning and design processes (Abdalla et al., 2011).

Since different types of assessments are used in these methods for evaluation of the different levels of the construction process, their classification becomes fairly complex. This has led to different classifications by different researchers in the field. Curwell et al. (2005) and Deakin et al. (2007), for instance, classified a range of assessment methods, tools and procedures in terms of 'pre-Brundtland' and 'post-Brundtland'. The 'pre-Brundtland' category included assessment methods in use such as cost-benefit analysis, contingent valuation, hedonic pricing method and travel cost method. According to Brandon and Lombardi (2011), since the Brundtland Report, there has been an evolution in assessment methods that recognize the supporting role of the natural environment and address a wide range of environmental impacts, hence developing many multi-criteria rating systems such as BREEAM (UK). While subdividing 'post-Brundtland' methods into environmental appraisal methods (for example ecological footprint and environmental auditing) and environmental assessment methods and rating systems (such as BREEAM, Leadership in Energy and Environmental Design (LEED), Sustainable Building Tool (SBTool), and so on), Brandon and Lombardi (2011) noted the presence of another category as statutory instruments which include Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA). These different types of assessment methods contribute towards progress in sustainability by evaluating the performance of products or processes (Brandon and Lombardi, 2011).

Among these environmental assessment methods, rating systems provide effective frameworks for assessing the environmental performance of buildings and integrate sustainable development practices into building and construction processes (Ali and Al Nsairat, 2009). Rating systems can be applied for a variety of purposes including the establishment of an initial measurement against which to calibrate future performance (base-lining); the provision of a basis for comparison with competitors (benchmarking); the establishment of a basis to choose and implement solutions with the objective of maximizing benefits (prioritization, decision support); and for the capture of evidence to support conformance standards, compliance with regulations or progress being made towards improvement (documentation) (Pearce et al., 2012). Rating systems have been developed at scales ranging from the organizational level, through materials and building products, to constructed items (buildings and other infrastructure).

2.4.1. Materials and Product Assessment

The environmental labelling and declaration of products aim to provide consumers with the means to make informed purchasing decisions based on the environmental characteristics of the products (Crawley and Aho, 1999) such as sustainable harvest of materials, resource use, waste and emissions during production and usage, and recycled content of products (Pearce et al., 2012). A variety of materials and product labelling systems can be found from various parts of the world as shown in Table 2-1.

2.4.2. Organizational Assessment

Environmentally and socially responsible investing is an approach taken by some market investors to steer the market towards more sustainable practices (Pearce et al., 2012). Environmental management systems such as the ISO 14000 series standard and the Eco-Management and Audit Scheme (EMAS) system within the European Union have aimed to change an organization’s management practices and operational patterns in order to improve environmental performance in the long term (Crawley and Aho, 1999). Pearce et al. (2012) referred to several systems that focus on measuring the sustainability performance of organizations such as the Global Reporting Initiative’s Triple Bottom Line and the SAM Corporate Sustainability Assessment.

2.4.3. Buildings and Infrastructure Assessment

A variety of approaches have appeared in the last two decades which can be applied for the environmental assessment of buildings and infrastructure. Reijnders and van Roekel (1999) have divided environmental assessment methods into two groups: a qualitative group based on scores and criteria and a quantitative group that uses the physical life cycle assessment (LCA) approach with quantitative input and output data on flows of materials and energy (Forsberg and von Malmborg, 2004; Sev, 2011).

Table 2-1: Materials and Product Labelling Systems

Labelling System	**Country of Origin**	**Description**
CarbonFree Certification	USA/ UK	This label is awarded to products that have eliminated or offset all carbon emissions associated with production. It covers carbon and GHG emissions preceding the use phase of the product.
China Environmental Logo	China	Initiated by the Ministry of Environmental Protection, this label provides for products such as construction materials and packaging.
Eco Mark	Japan	Applies to building products and considers the whole product life-cycle in terms of a range of environmental impacts.
Forest Stewardship Council (FSC) Certification	USA	Certifies sustainably harvested wood and wood products since initial harvesting to manufacture.
Water Efficiency Labelling and Standards (WELS)	Australia	Applies to building products and appliances and considers water use during the use phase of life-cycle.
Thai Green Label	Thailand	Applies to building products, water, energy, transportation and other products and evaluates over the whole life-cycle in terms of a range of environmental attributes.
Singapore Green Building Council certification (SGBC)	Singapore	Provides green building product certification.
Korean Ecolabel	Republic of Korea	Provides for a variety of products including building materials, forest products and packaging.

Sources: Pearce et al. (2012); SGBC (2013)

Some examples of the qualitative and criteria-based group are BREEAM (UK), LEED (USA), SBTool (International) and BCA Green Mark (Singapore) (Reijnders and van Roekel, 1999; Forsberg and von Malmborg, 2004: Sev, 2011). These qualitative methods are often based on the auditing of buildings, putting a score to each investigated parameter which results in an overall score for the building under assessment (Forsberg and von Malmborg, 2004).

Examples of the quantitative group with the LCA approach are Bees (USA), Building environmental assessment tool (BEAT) 2002 (Denmark), Life Cycle Analysis in Sustainable Architecture (LISA) (Australia), EcoQuantum (Netherlands), ATHENA Environmental Impact Estimator (Canada), Envest 2 (UK) and EcoEffect (Sweden) (IEA, 2004; Ali and Al Nsairat, 2009; Sev, 2011). These LCA scopes are however relatively narrow in comparison with criteria-based methods (Gu et al., 2006).

Crawley and Aho (1999) explained two basic methodological frameworks that have been developed for assessing the environmental impacts of a given object: EIA and LCA. Although both share the same objective of assessing environmental impacts, they differ in terms of their focus on environmental impacts. EIA is a comprehensive procedure which involves a range of planning problems such as social, administrative and physical, which is used as a means to identify the potential impacts of proposed developments to the environment (Brandon and Lombardi, 2011). EIA focuses on assessing the actual, site and context-specific environmental impacts of projects. Therefore, EIA methods are applied to large capital stock investments such as infrastructure projects. On the other hand, LCA methods assess non-site specific, potential environmental impacts and can be applied at both the product and project levels.

If construction projects were to be considered using the definition of environmental assessment methods described above, they can be seen as utilizing land extents and involving a range of construction activities, thus requiring attention to site and context-specific environmental impacts such as the impacts on surroundings, transport requirements and so on. Hence, most of these projects would require the application of the EIA method. At the same time, construction projects utilize large quantities of construction materials, products and other components over a definable life cycle, thus fitting into the scope of the LCA as well.

Therefore Crawley and Aho (1999) showed that construction projects require crossbreeds of EIA and LCA approaches such as the comprehensive criteria-based methods explained under the categorization offered by Reijnders and van Roekel (1999). This type of comprehensive criteria-based methods such as BREEAM (UK) and LEED (USA) is the focus of this study and these are discussed in detail in Chapter 3.

2.5. Summary

Construction and constructed items cause a range of environmental problems throughout their life cycles. The movement towards sustainable development emerged due to the increase in global awareness on the growing environmental problems. Similarly, the demand for sustainable construction has increased with more understanding on the environmental impacts of constructed items. The construction industry has responded to this demand in various forms.

Among them, environmental assessment methods provide systematic approaches to the evaluation of the environmental performance of construction projects and constructed items in reaching the goals of sustainable construction. In consequence, a range of environmental assessment methods have been developed at different levels such as the organization level, materials and product level, and for the assessment of constructed items: buildings and infrastructure. Environmental Rating Systems (ERSs) such as BREEAM (UK) and LEED (USA) were developed to address a wide range of environmental impacts of buildings and infrastructure. This type of ERSs is the focus of this study and the next chapter reviews such rating systems.

Chapter 3: Environmental Rating Systems (ERSs)

3.1. Introduction

This chapter reviews ERSs in construction including the types of assessments, their features and their benefits. The current role of ERSs in improving the environmental performance of construction projects is discussed and the wide application of ERSs in construction and the wide recognition they possess in the construction industry are highlighted. However, ERSs have not escaped criticism. Several such criticisms of ERSs, current trends, and some recommendations made by researchers in the area of study are discussed.

3.2. Environmental Rating Systems (ERSs)

As stated in Section 2.4.3, construction projects require crossbreeds of EIA and LCA approaches such as comprehensive criteria-based methods explained under the categorization by Reijnders and van Roekel (1999). The focus of the present study is this category of qualitative, comprehensive, criteria-based methods such as BREEAM (UK) and LEED (USA). A list of such methods developed in different countries and the different terms that have been used by their developers are given in the Table 3-1. Most of the developers of these assessment methods identified them as ‘rating systems’. In this study, the term Environmental Rating Systems (ERSs) is used to identify this category of criteria-based environmental assessment methods. Cole (2003, p.2) provided a definition for ERSs as, “an objective and comprehensive means of simultaneously assessing a broad range of environmental considerations against explicitly declared criteria, and offering a summary of overall performance”.

Table 3-1: Different Terms Used for ERSs

Name (Year of Publication)	**Country of Origin**	Assessment method	Rating System	Assessment System	Tool	Benchmarking scheme	Assessment scheme	Rating Scheme	Certification system
Building Assessment									
BREEAM **-** Building Research Establishment Environmental Assessment Method (1990)	United Kingdom	√	√						
LEED **-** Leadership in Energy and Environmental Design (1998)	USA		√						
Building Construction Authority (BCA) Green Mark (2005)	Singapore					√			
CASBEE **-** Comprehensive Assessment System Built Environment Efficiency (2001)	Japan	√		√	√				
Green Star (2003)	Australia		√						
HK BEAM **-** Hong Kong Building Environmental Assessment Method (2009)	Hong Kong	√							
GBI **-** Green Building Index (2009)	Malaysia		√						
Estidama (the Arabic term for sustainability) Pearl Rating System (2010)	United Arab Emirates		√						
GRIHA **-** Green Rating for Integrated Habitat Assessment (2005)	India				√				

GBCSL - Green Building Council Rating System in Sri Lanka (2011)	Sri Lanka		√						
LOTUS Rating Tools (2011)	Vietnam				√				
TREES - Thai's Rating of Energy and Environmental Sustainability Rating System (2012)	Thailand		√						
BERDE - Building For Ecologically Responsive Design Excellence (2007)	Philippines		√						
Korea Green Building Certification (2002)	Korea								√
Green Globes Rating System (2000)	USA		√						
NatHERS - Nationwide House Energy Rating Scheme (1993)	Australia							√	
Green Star - New Zealand Green Building Council (2007)	New Zealand				√				
DGNB System - German Sustainability Building Council (2008)	German								√
Infrastructure Assessment									
CEEQUAL - Civil Engineering Environmental Quality Assessment and Awards Scheme (2003)	UK						√	√	
IS - Infrastructure Sustainability Council of Australia (2012)	Australia		√					√	
Building Construction Authority (BCA) Green Mark (2009)	Singapore					√			
Envision Sustainable Infrastructure Rating System (2012)	USA		√						

Sources: Developers' Websites

BREEAM in UK was the first ERS published for the assessment of environmental performance of buildings (Cole, 1998, 2005; Cole et al., 2005). There has been a rapid increase in the number of ERSs for assessing buildings world-wide thereafter (IEA, 2004). According to Cole et al. (2005), initially, the development of ERSs was largely an exercise in structuring a broad range of existing knowledge and considerations into a practical framework rather than one requiring or demanding new research.

However, environmental assessment with ERSs has now become a defined realm of enquiry with more rigorous explorations of weighting protocols, performance indicators and effectiveness (Cole et al., 2005). Today, there is active involvement in the development of different ERSs in the building sector (Haapio and Viitaniemi, 2008) in research, and policy circles, both independently and collaboratively (Poston et al., 2010). Different organizations and research groups have contributed to new knowledge in ERSs. For example, international networks and initiatives such as the Green Building Challenge (GBC) and World Green Building Council (WGBC) have promoted and supported the development of ERSs and international standards (Todd et al., 2001; Poston et al., 2010). As a result, there is a significant increase in the number of national systems since the year 2000 (Poston et al., 2010). The environmental agenda has significantly increased the number of potential performance criteria of relevance to design and precipitated a corresponding increase in interest and research activity to develop comprehensive building environmental assessment methods (Cole, 1998). As a result of this evolution in the field, today there are many ERSs worldwide for use in the assessment of buildings in both developed and developing countries as shown in Table 3-1.

3.3. Voluntary Application vs. Regulatory Application of ERSs

In general, the existing ERSs are voluntary in their application. Lee (2013) showed that the flexibility that these ERSs offer to clients in reaching their targets while helping them improve their image promotes the application of ERSs. Cole (1998; 1999), however, stated that ERSs should be credible in their ability to improve the environmental performance of projects. Cole

(1999) thus showed that voluntary ERSs have to satisfy these conflicting requirements at the same time. Lee (2013) also stated that it is debatable whether the "rigorous and stringent" or "relaxed and pragmatic" approach is preferred in the case of ERSs.

Although most market-based ERSs were originally developed to serve as voluntary systems, public authorities have been increasingly adopting them as a basis for specifying the environmental performance levels of construction projects while compliance with their requirements is increasingly being made a condition for the approval of building projects (Cole et al., 2005; Lee, 2013). Poston et al. (2010) stated that a number of ERSs have benefited from endorsement by national governments.

Schweber (2013) showed that in the UK, even the policy makers such as Department for Environment, Food and Rural Affairs (DEFRA) consistently insist on the role for ERSs in achieving the goals of sustainable development. Lee (2013) also stated that UK government departments now require BREEAM certification for their buildings (Lee, 2013). A number of public- and private-sector organisations in the UK have either specified or encouraged the use of BREEAM (BRE, 2013) in their buildings. Some such examples are given below:

- DEFRA, which comes under the central government, through the Government Buying Standards, requires all buildings on the Government Estate to achieve a minimum BREEAM rating of 'Excellent' for new buildings and a minimum BREEAM rating of 'Very Good' for all major refurbishments.

- Under the Welsh government, the 'Planning Policy Wales,' since September 2009, requires that planning applications received for non-residential development which either have a floor space of 1,000 m^2 or more, or will be carried out on a site having an area of one hectare or more, to meet the BREEAM 'Very Good' standard and to achieve the mandatory credits for 'Excellent' under the criteria "Reduction of CO_2 Emissions".

- The Northern Ireland Executive requires all new or refurbished buildings occupied by government departments to undergo BREEAM assessment (or the CEEQUAL equivalent) and to meet at least the 'Very Good' standard.

- In the case of the Department for Education (DfE), and Department for Employment and Learning (DEL), all projects are encouraged to aim for a BREEAM 'Excellent' rating.

- In the education sector too, certain scale of projects is required to achieve the BREEAM (or equivalent) 'Very Good' rating.

- In the private sector, Marks and Spencer has aimed for all its new stores and warehouses to achieve the BREEAM 'Excellent' ratings.

- The John Lewis Partnership has stated that all new shops will be assessed using BREEAM to achieve a minimum 'Very Good' standard.

Similarly, the LEED certification is also increasingly being recognized and specified by organizations and public agencies for buildings, both nationally and internationally (Kenline, 2012; USGBC, 2013; Lee, 2013). The U.S. government, under the General Services Administration (GSA), which governs all federal buildings, has chosen LEED to certify all of their federal buildings (Kenline, 2012). LEED has been recognized by the Public Works and Government Services Canada (PWGSC) too, with all its new construction designs required to go through the assessment to meet a LEED Silver equivalent (Cole, 2006).

In Singapore, the Building Control Act has put in place the Building Control (Environmental Sustainability) Regulations, requiring a minimum environmental sustainability standard that is equivalent to the "Green Mark Certified Level" for new buildings and for existing ones that undergo major retrofitting. Projects that are submitted to the Urban Redevelopment Authority (URA) for planning permission on or after 15 April 2008 are subject to this requirement. BCA's Second Green Building Master Plan also indicated in 2009 that projects developed on land that is sold under the Government Land Sales (GLS) Programme; and sites in selected strategic areas are subject to higher Green Mark standards. Under this initiative, several locations have been identified where designs must achieve the Green Mark Platinum Rating or Green Mark Gold^{Plus} Rating. In the case of building works that are subjected to these requirements, the Green Mark Certificate should be submitted for the project along with its application upon completion of the building works, in order to obtain the Temporary Occupation Permit (TOP) or the Certificate of Statutory Completion (CSC).

Australia is a part of the growing international movement towards the development of ERSs and tools. The Australian government has recognized ERSs as assessments and benchmarks that can be used to set minimum regulatory standards and to encourage better levels of practice that go beyond minimum standards (Your Home, 2013). For example, in most areas of Australia, the Building Code of Australia requires a minimum energy star rating of five stars for new single dwellings as assessed by the Nationwide House Energy Rating Scheme (NatHERS). While this standard of 5 out of the 10 stars available is not the best practice, the standard specified is considerably higher than that obtained in terms of the average performance of homes built prior to the regulation. In many states, new homes are required to earn at least 5 stars. In New South Wales State, homes require Building Sustainability Index (BASIX) scores instead of star ratings (Your Home, 2007). The Green Building Council, Australia (GBCA), moreover, works with local, state and federal governments across the country and some local governments have consequently decided that regulation is appropriate for their community, now requiring large commercial projects within their jurisdictions to achieve a minimum of four Green Star ratings (GBCA, 2013).

In the case of Hong Kong, with more than 30% of the projects assessed, the Hong Kong government represents the largest HK-BEAM client (Cole, 2006). Lee (2013) noted that development projects for public buildings in Hong Kong now require BEAM Plus certification. BEAM assessment system has introduced some mandatory prerequisites that are aligned with current trends in industry standards and regulations. For example, the BEAM Plus Version

1.2 for New Buildings and Existing Buildings have become mandatory since January 2013 (BEAM Society, 2013).

CASBEE in Japan is also now employed as a tool for developing and reviewing mandatory reports (Evans et al., 2009) while several local authorities in Japan have called for CASBEE certification as part of their building approval requirements (Lee, 2013). In the Philippines, the Department of Energy (DOE) has officially endorsed BERDE as the “National Voluntary Green Building Rating System” and the Philippine Green Building Council (PHILGBC) has implemented the BERDE Program in support of DOE’s mandate to promote energy efficiency in the Philippines (PHILGBC, 2013a; Asia Green Buildings, 2013).

In some countries, ERSs are accepted as an alternative route to complying with building regulations as evident from some of the examples given above. This integrated approach provides an incentive for construction clients to accept ERSs and to comply with building regulations at the same time without replicating the cost of documentation.

3.4. Features and Components of ERSs

There are several inherent features and components of ERSs and this section explains a few of them such as comprehensiveness, weighting systems, communication of the results and the inclusion of qualitative criteria.

3.4.1. Comprehensive Set of Environmental Issues and Criteria

ERSs provide comprehensive assessment methods which assess a broad range of environmental considerations. However, improving the comprehensiveness of an assessment by increasing the number of assessment criteria could diminish the ability of building owners, users and the public to interpret the results of the assessment with each additional criterion (Cole, 1998). Also there are practical and cost implications associated with data collection and assessment. Despite these issues, Cole (2005) explained this comprehensiveness as one of the factors which have led to the success of ERSs.

These criteria are determined based on the type of impact of the constructed items on the environment. The weightings are assigned a value in terms of the seriousness of each impact in relation to the other criteria (Fenner and Ryce, 2008). Fenner and Ryce (2008) noted that a well-recognised definition and general approaches for green buildings are yet to be established to provide the basis for ERSs.

3.4.2. Weighting Systems

According to Lee et al. (2002), weighting is at the heart of all assessment systems since it dominates the overall performance score. Thus weighting is inherent to ERSs (Todd et al., 2001). However, although all existing methods assign performance points to various environmental criteria, at present there is no readily used satisfactory methodological framework to guide the assignment of weightings (Cole, 1998). Ding (2008) also identified the absence of a logical, commonly agreed and non-subjective theoretical basis for deriving weighting factors as a major issue in ERSs. Therefore weighting remains a controversial aspect of ERSs, which is dependent on a greater understanding of the environmental impacts of construction. As one attempt to address this issue, the GBC framework provides a default weighting system and encourages users to change the weightings based on regional differences (Ding, 2008). A similar approach is adopted in the CEEQUAL (UK) international version.

The allocation of a different number of assessment points to different criteria implies an attribution of significance (Cole, 1998) and is a better approach in terms of prioritizing environmental considerations, rather than assigning equal points to all criteria. Todd (1996) stated that in deriving appropriate weightings, the key to understanding the relative importance of environmental criteria lies in the potential environmental impacts on endpoints of concern. Weighting is the mechanism by which a very large number of performance criteria are reduced to a smaller and more manageable number (Cole, 1999) and it is important for communicating the results of the assessment.

3.4.3. Communication of the Results

Communication of the results of assessment using ERSs is important where the complete performance profile of the building is evident and the 'story' of the performance is told directly in a coherent and informative way (Cole, 1999). The terms 'certification', 'rating' and 'labelling' are often used interchangeably to indicate the final overall results of the assessment processes which typically takes the form of a singular, easily recognizable designation. For example, descriptive categories such as 'Fair', 'Good', 'Very Good' or 'Excellent' in BREEAM, the 'Bronze', 'Silver', 'Gold' and the best or 'Platinum' performance benchmarks in LEED, and the number of stars in the Green Star system are used. However, these do not reflect the nature of the criteria or their performance under each criterion separately in the output (Cole, 1999).

3.4.4. Qualitative Criteria

As comprehensive assessments, ERSs accommodate both quantifiable performance criteria (such as energy use, water use or GHG emissions) and qualitative criteria such as the ecological significance of the site (Cole, 1998). Although qualitative criteria cannot be readily evaluated compared to quantitative criteria, a wide range of performance issues in projects require qualitative metrics to evaluate buildings comprehensively. They are therefore worthy of inclusion in ERSs (Cole, 1999).

3.5. Benefits

There is a range of benefits from the use of ERSs for environmental assessment in construction such as providing a common set of criteria and targets to measure environmental performance of constructed items, providing design guidelines, gathering and communicating information on the performance of constructed items, and more generally raising awareness of, and promoting, sustainable construction. Some of these benefits are discussed in this section.

3.5.1. Providing a Common Yardstick to Measure Performance

The widespread use of ERSs leads, firstly, to the declaration of a common set of key environmental issues with relative priorities assigned to them (Cole et al., 2005; Fenner and Ryce, 2008) in terms of criteria and weightings, thus providing targets and a common yardstick for measuring progress towards sustainability. Therefore, ERSs help to organize information in an explicit manner (Cole et al., 2005). Thus, building owners striving for higher environmental standards have a means of demonstrating their efforts (Cole, 1998; 1999).

With this set of criteria and targets, ERSs provide a methodological framework to identify and measure the success at meeting a level of performance, that is, how well or poorly a building is performing, or is likely to perform, against a declared set of criteria (Cole, 1998), to monitor environmental performance (Ding, 2008) and as a guidelines for remedial work **(**Cole, 1998). With this framework, ERSs have the ability to offer a recognizable structure for assessing environmental issues and the environmental performance of buildings. They, therefore, contribute a lot to furthering the promotion of higher environmental expectations, and directly and indirectly influence the performance of buildings (Cole et al., 2005; Cole, 2005).

3.5.2. Assisting the Design Decisions and Process

According to Cole (1998), since ERSs present an organized set of selected environmental criteria, they naturally communicate to building owners and design teams what are the most significant environmental considerations. As such, ERSs are increasingly being used as design guidelines, even though they were not originally intended to do so (Crawley and Aho, 1999) or were not specifically designed to do so (Cole, 1998). Thus, ERSs provide a structured means of incorporating performance targets and criteria into the design process (Crawley and Aho, 1999).

Furthermore, Ding (2008) identified ERSs as offering some insight into comparing design solutions. Fenner and Ryce (2008) saw this as a means to inspire design teams to explore alternatives and to search for enhanced environmentally sustainable options. They also offer insights to the design team on highlighting priority issues and identifying possible trade-offs between options, and thus provide the basis for making informed design decisions during design development (Cole, 1999). Ding (2008) showed this as an important benefit of ERSs during the design stage since the early incorporation of environmental issues in the design process enables better environmental performance.

3.5.3. Increasing Awareness and Collaboration between Stakeholders

Several authors, among them, Cole et al. (2005) and Fenner and Ryce (2008), identified greater communication and interaction between members of the design team and various sectors within the building industry as an important indirect benefit of the widespread use of ERSs due to the broad range of issues incorporated into the ERSs. Thus, environmental assessment methods encourage greater dialogue and teamwork (Cole, 1998; 1999; Cole et al., 2005). The widespread adoption of ERSs is moreover increasingly influencing associated manufacturing industries and materials and product suppliers to re-evaluate production processes and to develop new environmentally beneficial products and services (Cole, 2005; Cole et al., 2005). It is thus also fostering innovation within the manufacturing and supply sectors (Fenner and Ryce, 2008).

More generally, according to Cole (1998), the ERSs have made significant contributions to the understanding and public awareness of building-related environmental issues and the environmental performance of buildings. Fenner and Ryce (2008) also showed that ERSs are driving not only designers, builders and building owners but also other stakeholders in the construction industry supply chain towards sustainable solutions which is, in turn, encouraging the whole community to adopt sustainable construction rather than just motivating companies or individuals towards the creation of isolated, environmentally friendly structures. Likewise, the increasing popularity of ERSs can contribute to the integration of methods and practices favouring sustainable construction which can achieve the goals of sustainable development (Ding, 2008; Poston et al., 2010).

3.5.4. Competitive Advantage in the Market

Cole (1998) saw ERSs as motivating the gathering and organizing of detailed information on buildings and identified a range of benefits of such information. First, they are beneficial to the building management and building owners themselves for the purpose of identifying priorities for future administration measures such as lower operating, financing and insurance costs, lower vacancy rates and building retrofits which will increase marketability and ensure the place of the property within a changing market-place. Secondly, such information can be used to structure environmental information for new building designs and major renovations as well as to formulate effective environmental design strategies in a rapidly expanding field of knowledge (Cole, 1998).

The summaries of building performance provided by ERSs can be used thus for purposes of communication with stakeholders on environmental performance (Cole et al., 2005) and therefore it is beneficial to building owners as a means to communicate to prospective tenants the inherent environmental qualities of the building (Cole, 1998). For example, under the LEED Canada scheme, data pertinent to certified projects are added to an online database maintained and hosted by the Canada Green Building Council with non-technical presentation and content which enable the general public to examine the building's primary use as well as the green technologies incorporated into its construction and its certification rating (Fenner and Ryce, 2008).

The designers and owners also benefit from successful certifications under ERSs in terms of the increased value of constructed items and the market niche created for such items (Fenner and Ryce, 2008). For example, recent studies in Australia demonstrate that the mandatory disclosure of energy efficiency shows a very strong correlation between star ratings and house value which is approximately 3% for each star (for example a house worth $

400,000 increases its value by approximately $12,000 per star) (Your Home, 2013).

3.6. Criticisms

There are many criticisms regarding both existing ERSs and the development process of ERSs. Among the major criticisms are the complexity, the lack of involvement during design conceptualization, the assessment of predicted rather than actual performance, the ability they afford to score points with criteria that may not account for physical performance, the lack of attention to the wide sustainability aspects, the absence of absolute measures, and the problems that crop up when ERSs are imported from one region to another. These will be discussed in this section.

3.6.1. Complexity

As stated in Section 3.4.1, ERSs are generally comprehensive in addressing a range of broad environmental issues but some ERSs consequently are too long. For example, Lee (2013) showed that BREEAM, LEED, BEAM and Evaluation Standard for Green Building (ESGB) in China include 114, 107, 88 and 80 total numbers of criteria respectively. Currently some ERSs have also taken into account the wide sustainable development objectives (this trend will be discussed in Sections 3.6.6 and 3.7.3), thus tending to include factors such as social, cultural and financial aspects as well. But, as Ding (2008) showed, this comprehensive approach has led to complex systems which require large quantities of detailed information in the evaluation process which may jeopardize the usefulness of the system by making assessments cumbersome. Hence it is a challenge to develop effective and efficient ERSs which also maintain completeness in coverage.

3.6.2. Assessing when the Design is almost Finalized

The more effective way to achieve sustainability in a project is to consider and to incorporate environmental issues at a stage before a design is even conceptualized. As stated in Section 3.5, ERSs can act as design guidelines as well. However, normally, the assessment process is carried out when the design of the project is almost finalized (Crawley and Aho, 1999; Soebarto and Williamson, 2001). Therefore, as Ding (2008) showed, for ERSs to be useful as a design guideline, they must be incorporated early in the conceptual design phase in order to allow for early collaboration between the design and assessment teams in considering environmental issues. Such collaboration would ensure that assessments will not rely only on detailed design information (Ding, 2008) but influence the design in a more effective way.

3.6.3. Ability to Score Points even without Good Performance

According to Cole (1999), there is evidence to show that a building's performance in actual practice is often markedly different from that anticipated or predicted during the design. However, actual performance of the building in use is the most significant measure of success within the sustainability agenda. A study by Newsham et al. (2009) conducted using data from 100 LEED-certified commercial and institutional buildings showed that although LEED-certified buildings save substantial amounts of energy compared to other conventional buildings, the measured energy performance of LEED-certified buildings had little correlation with the certification levels or the number of energy credits achieved by the buildings at design time. This is because, as Poston et al. (2010) pointed out, most ERSs focus on assessment during the design and construction phases before actual occupation of the building or when the buildings are first commissioned (Fenner and Ryce, 2008).

Though this was the case earlier, ERSs are gradually beginning to address this issue today. In a comparison of five ERSs, namely BREEAM, LEED, BEAM, ESGB and CASBEE, Lee (2013) showed that all five systems eventually assess actual building performance. BREEAM and ESGB cover various phases of the project development including pre-design, design, construction and operations but certification can only be obtained during the operation phase, by referring to both predicted performance and actual performance data so that they directly evaluate 'actual' performance. In the case of the other three systems, they adopt a two-phase certification where the assessment can be made in the pre-design, design and construction phases though not in the operation phase. Thus, certifications are based on ‘predicted’ performance. However, they have introduced a recertification requirement within a period of three to five years from the last certification which is based on actual performance data.

3.6.4. Criteria without Direct Physical Impacts/Performance

Several ERSs currently evaluate management and leadership factors. For example, points are awarded for the appointment of environmental officers or for conducting desk studies and risk assessments to evaluate the documented commitment of construction clients. Although Cole (1998) tried to explain that such issues are important to explain performance improvements and practices, yet it can be argued that it is not necessary to explicitly evaluate such management practices since they are captured within other physical performance measures. A project can score a considerable portion of total points with these factors but even with the appointment of such environmental officers and even after a detailed assessment, if the actual physical performance is not achieved, the real environmental impacts of the project can be misinterpreted in the final result communicated. Although such criteria are used in voluntary systems to increase the potential scores and to encourage clients towards documented commitment, it might distort the real picture with regard to the actual environmental performance of buildings.

3.6.5. No Negative Points

Cole (1998) asserted that the award of a proportionally higher number of points with increased performance intervals is clearly the most appropriate for voluntary systems where the objective is to encourage building owners to aspire to greater levels of performance. However, given the incentive nature of many existing methods, only positive points are typically assigned; thus while points are given for what is included, no points are deducted for what is not included. Although this motivates building owners to adopt the ERSs, the current system therefore may not reflect the real environmental impacts/performance of the projects. Moreover, although the inclusion of negative points in ERSs may not be practical in a voluntary context, in a regulative context given that governments are taking an interest in using the ERSs for regulatory purposes, this is somewhat possible because the purpose of ERSs should be to enhance environmental performance rather than to merely enable the clients to earn higher scores.

3.6.6. Absence of a Wide Range of Sustainability Aspects

Cole et al. (2005) emphasized that broadening the scope of discussion beyond environmental responsibility to embrace the wide agenda of sustainability is an increasingly necessary requirement and that ERSs should be re-casted under the umbrella of sustainability to include social and economic aspects as well. Cole (1999), Cooper (1999) and Todd et al. (2001) showed that ERSs which predominantly focused on "environment" in terms of environmental protection and resource efficiency have only limited reach in terms of assessing socio-economic contexts. Likewise Ding (2008) stated that ERSs such as BREEAM and Building Environmental Performance Assessment Criteria (BEPAC) are not designed to address broad sustainability issues.

According to Poston et al. (2010), most studies comparing ERSs are agreed that ERSs do not sufficiently cover the three aspects of the "Triple Bottom Line" of sustainability (three dimensions: economic, social and environmental aspects) (Haapio and Viitaniemi 2008; Sinou and Kyvelou 2006; Cole 2005). Moreover, in a comparison of 30 building assessment methods, Poston et al. (2010) showed that very few methods covered the Triple Bottom Line and that current ERSs principally focus on the projected energy consumption and environmental impacts although it is essential for projects to aspire to the delivery of a high degree of sustainability that considers a wide range of impacts. El-Adaway and Knapp (2012) also supported this criticism by saying that as ERSs have been designed to address mainly the environmental aspects of construction, do not interact with the broad socio-economic structures. Furthermore, they argued that decision makers find it difficult to make judgments which are consistent with sustainability goals for development due to this narrow focus of the current ERSs.

Moreover, Ding (2008) criticised the absence of financial aspects in some ERSs since the developers' primary aim of a development project is to have an economic return. Since some projects may be environmentally sound but expensive to build, Ding (2008) suggested that both environmental and financial aspects must be considered as parts of the assessment because if economic returns are not satisfactory, the project would be less attractive to developers even though it may be environment friendly. Soebarto and Williamson (2001) also found that most ERSs exclude cost and that only in some systems is part of the total cost included.

Lee (2013) showed that there are new systems that have been developed in line with this criticism. These will be presented in Section 3.7.3. Despite these attempts, according to Poston et al. (2010), the concern with broad sustainability objectives is still insufficient in ERSs. For example, while LEED had developed its criteria for Version 3 to cover a broader and more sustainable analysis, the coverage of economic and social aspects is still limited (Poston et al., 2010). However, according to Lee (2013), whether assessments should include 'financial' impacts remains still a debatable issue that is unresolved.

3.6.7. No Absolute Measures

According to Cooper (1999), one deficiency in ERSs is the assessment of performance against relative, rather than absolute, criteria. Ding (2008) also expressed a similar view and proposed to quantify criteria such as resource usage and energy consumption in order to arrive at an absolute assessment of performance. Likewise, the main criteria on environmental assessment should be based on the importance of addressing the environmental impacts on the regional and global scale. However, sufficient data are not available to measure all criteria in absolute measures. Although relative assessments do not reveal the global carrying capacity appropriated by the development, due to the absence of absolute measurements, "consensus-based" weighting have to be used and in this approach, groups of experts or stakeholders rank various elements, such as environmental issues, in terms of the relative importance of environmental issues in the concern (Todd et al., 2001).

3.6.8. Importing ERSs from One Region to Another

Importing assessment methods originating in developed countries to other regions has been greatly assisted through the active participation of many countries in international programmes (Cole, 2005) and initiatives such as the GBC and Sustainable Building Challenge (SBC) (IISBE, 2013). Lee (2013) stated that many countries have developed new systems with reference to assessment systems that originated in developed countries.

Driven by factors such as the demand for 'brand recognition' in a global market, the desire for international standards, and the interest of the owners of some assessment systems to expand the adoption of their systems abroad, there has been an increased international use of the two most established methods: BREEAM and LEED (Cole, and Valdebenito, 2013). However, Cole (1998) showed that although many countries are using BREEAM, it was not originally designed to accommodate national or regional variations and that therefore the various customized versions do not emerge logically out of the source documents. The case is similar with LEED as well.

Lee (2013) further stated that these reference systems were themselves developed to address specific regional concerns, which make their configuration for application to another regime a difficult proposition. For example, a study by Chandratilake and Dias (2013) compared domains in nine ERSs developed in different countries with relevant national statistics and showed that good correlation exist between weightings and national indicators. Cole (2005) showed that despite the benefits associated with this exchange and ‘borrowing’, the dangers of homogenization and reduced sensitivity to the acknowledgement and promotion of regionally appropriate design strategies is always present. Cole (2005) further stated that importing ERSs from their author countries to another is recognized as problematic. For example, many ERSs emphasize energy use rather than water use but the water issues should be given priority if these ERSs are applied in the Gulf region (Lee, 2013).

In a study carried out by Alyami et al. (2013) in Saudi Arabia, the authors tested an overarching hypothesis, namely, that the leading international ERSs such as BREEAM and LEED are unsuitable for the country given its context. The hypothesis was tested using the Delphi technique and the findings strongly suggested the inapplicability of these ERSs for the Saudi Arabian context and the need therefore to develop further categories and criteria for environmental assessment of buildings in Saudi Arabia.

The concern with regional variations has increased with expanded consideration of a wide range of aspects. According to Cooper (1999), these problems would become acute if the range of considerations is expanded to address the social and economic aspects of sustainability. Cole (2005) showed that since the social and economic concerns of developing countries are far more pressing than those of developed countries, the domestic constraints on the progress of environmental sustainability too would be qualitatively different.

3.7. Trends in the Field of ERSs

3.7.1. Acknowledgement of Regional Variations

As explained in Section 3.6.8, when ERSs are imported from one region to another, some criteria and priorities may appear inappropriate and, hence, the adaptation may lead to problematic results. However, the weighting systems can offer revisions of the assessment scale in order to reflect regional variations up to a certain extent (Ding, 2008).

According to Gibberd (2001), priorities in developed and developing regions differ; where the emphasis in the former has been on maintaining standards of living while reducing resource depletion and environmental damage, in the latter, where the average standard of living is far lower than in developed countries, the emphasis has been on meeting basic human needs in the main since they are not being met in many cases. In developing countries, therefore, according to Gibberd (2001), the emphasis should be on development that aims to satisfy these basic needs while avoiding negative environmental impacts.

Cole (2005) showed that whereas some environmental criteria related to resource use and loadings can be readily reconfigured to acknowledge different regional and geographical contexts, many other criteria cannot be so readily reconfigured. However, the need for and importance of region-specific ERSs are being identified and many countries have either developed or are in the process of developing their own assessment systems (Lee, 2013).

For example, Ali and Al Nsairat (2009) developed the SABA Green Building Rating System for residential units in Jordan through a research which studied international ERSs such as LEED, CASBEE, BREEAM and so on, defining new criteria to accommodate the local conditions of Jordan from the environmental, social and economic perspectives. A study by Alyami et al. (2013) also identified a set of new criteria for an ERS for use in the Saudi Arabian context.

3.7.2. Life Cycle Coverage

Ding (2008) showed that in the absence of life-cycle coverage, ERSs would not give a balanced assessment between a development project and its impact on the environment. Cole (1998) showed the adoption of life-cycle assessment methodologies as a contextual factor in ERSs and explained the importance of taking into consideration the whole life-cycle of constructed items in ERSs.

For example, DGNB in Germany and Pearl rating system in the United Arab Emirates address LCA within assessment and reassessment (Poston et al., 2010) while HK BEAM and BREEAM consider life cycle energy assessment (Lee, 2013). In addition, the inclusion of embodied energy assessment would necessitate a consideration of the energy used in raw building materials and products as well (Lee, 2013).

3.7.3. Inclusion of Other Sustainability Aspects

Early ERSs have been widely criticised for not focusing on a wide range of sustainability aspects, in particular, the lack of concern over social and economic aspects as discussed in Section 3.6.6. In response to this criticism, there is a trend in the field of ERSs to consider a wide range of issues in order to cover Triple Bottom Line. In a comparison of ERSs, Poston et al. (2010) showed that although very few ERSs cover Triple Bottom Line, the number is significantly high when compared with those studies undertaken between 2004 and 2006 with regard to the Triple Bottom Line (Walton et al., 2005; Cole, 2006; Sinou and Kyvelou, 2006). For example, DGNB in Germany, VERDE in Spain, Lider-Ain in Portugal and Pearl rating system in UAE specifically covered Triple Bottom Line aspects (Poston et al., 2010). According to Cole (1998; 2005), the understanding of sustainability as an emerging factor has profoundly affected ERSs.

Studies by Cole et al. (2005) and Fenner and Ryce (2008) showed that realignment of the focus of ERSs to address the Triple Bottom Line has to be carefully orchestrated because a dramatic change in assessment focal points runs the risk of taking attention away from the most important focus: that is, improving the environmental performance of buildings.

Another issue having to do with the inclusion of sustainability aspects in the ERSs is to determine which view of sustainability is to be followed. Poston et al. (2010) stated that they compared sustainability assessment methods in terms of the generally accepted Triple Bottom Line of sustainability, but stated that the selected methods were based on different approaches to sustainability, expressing uncertainty simultaneously regarding whether any of them is the most appropriate method to achieve 'realistic' sustainability.

Cole (1998; 1999) explained that it is difficult to place the ERSs within the context of sustainability as the primary focus of ERSs is environmental performance and not the social and economic dimensions to sustainability. According to Poston et al. (2010), one difficulty with regard to including other sustainability aspects into ERSs is the requirement of more qualitative data and the subsequent increase in subjectivity.

On the other hand, in construction projects, economic aspects are given priority by private-sector developers. Hence, the developers together with the project team will strive to make the project economical. Thus, economic aspects would naturally be addressed by the project team. The community and other affected parties would be concerned with the projects' social impacts which will be addressed due to public pressure and other political agendas. However, the voice raised on behalf of the natural environment will not be as powerful as the socio-economic aspects in development projects. This can have more severe consequences in developing countries.

Moreover, though previous ERSs had been criticized for the absence of wide sustainability objectives with the increasing popularity of the view of 'sustainability' as the 'balance between three or more sectors', this approach to sustainability is not theoretically established, with criticisms of this view of sustainability categorizing it under the 'weak sustainability' concept. More details on these views and different concepts are presented in Chapter 6. Poston et al. (2010) also showed that policy agendas have tended to operate around this view which has allowed for tradeoffs to be part of the agenda between the three dimensions of the Triple Bottom Line. Hence, to move towards an approach more focused on environmental limits, a 'stronger' interpretation of the concept should be followed in ERSs.

3.8. Recommendations

3.8.1. Methodological Transparency

Crawley and Aho (1999) stated that certain requirements must be met by ERSs both from a philosophical and a practical point of view. Of these, methodological transparency is one of the most fundamental requirements. Stakeholders must be able to have access to, and understand, the assumptions, data and other methodological issues influencing the outcome of assessments. This helps to improve the performance of constructed items and projects that apply such systems.

3.8.2. Nesting Principle

Fenner and Ryce (2008) argued that a top-down approach is appropriate for ERSs which first defines the general requirements for the sustainability of constructed items and then develops the detailed parameters under each requirement. A similar approach is followed in the "nesting principle". The idea in nesting is to allow the system to be used consistently at different levels of detail (Crawley and Aho, 1999). Nesting would allow for performance targets to be specified on the highest abstraction level and the compliance of designs with the targets to be verified using methods indicated on the highest level of detail (Crawley and Aho, 1999). The nesting principle provides an elegant means to view performance in detailed or general terms, and to clearly distinguish between qualitatively different environmental issues (Cole, 1999).

The nesting principle would increase the methodological transparency explained in Section 3.8.1 of ERSs as well as other benefits. Cole (1998) suggested that future developments of ERSs should adhere to a nesting principle in which the criteria considered in the assessment can be described or assessed at successively detailed levels, but each logically connected to other levels. Defining the end goals provides a means for ERSs to continue in a coherent direction (Fenner and Ryce, 2008).

According to Cole (1998), the ability of ERSs to ‘open-up’ the assessment framework by using a nesting principle would not only offer the potential for greater transparency of the process (at a time when it is critical to understand the basis upon which assessments are being made), but also provide the ability to revisit and adjust performance criteria as the field gains in experience and understanding regarding the linkages between the various performance issues.

Future efforts will make the link between building design and building assessment more seamless, possibly by providing either a parallel set of criteria or a further level of detail within a hierarchical structure logically related to the assessment criteria (Cole, 1998). For example, Ugwu and Haupt (2007) followed a hierarchical structure in developing an assessment system for infrastructure in South Africa.

3.8.3. Type-specific ERSs

Many ERSs for buildings consider different types of building projects separately such as residential, commercial and so on. Project scale (Abdalla et al., 2011) and project type (Haapio and Viitaniemi, 2008) are important factors in categorizing ERSs because the different types of projects have different environmental impacts, which in turn necessitates assessments carrying different benchmarks (Kajikawa et al., 2011). Fenner and Ryce (2008) also emphasized the importance of having type-specific ERSs for more effective application of assessments. For example, while LEED operations in the USA includes several type-specific systems, the Canada Green Building Council chose to adopt a single system because of the relatively small building population in Canada in comparison with that of the USA though this limited the scope of the system in terms of where it can be applied. Cole et al. (2005) also stressed the importance of type-specific versions of ERSs.

Although there are few infrastructure-related ERSs published so far, the importance of having type-specific ERSs to assess infrastructure has already been recognized with an increasing tendency to focus more attention on them. The existing infrastructure-related ERSs are, however, general to all types. Hence, there is still a dearth of type-specific ERSs for assessing infrastructure projects though different types of infrastructure cause significantly different types of environmental impacts.

3.8.4. Stakeholder Participation

Cooper (1999) criticized ERSs for not dealing with public participation. Ding (2008) showed the importance of stakeholder participation in identifying the criteria and sub-criteria for ERSs and in deriving weights to reflect the level of importance of criteria and sub-criteria during the feasibility stage of a project. For example, the United States Green Building Council (USBGC) has started an approach that involves opening up a public comment period for new versions of LEED ratings before they are launched. This allows the stakeholders and general public to participate in the development of ERSs.

3.9. Summary

This chapter reviewed literature on ERSs; the types of assessments, features and benefits of ERSs, criticisms and recommendations for future ERSs, and trends in the domain of ERSs. Some facts noted in this review were considered in the study when proposing the conceptual framework for ERSs.

Firstly, there is an emerging trend in the field of environmental assessment to consider a wide range of sustainability aspects in ERSs. It was therefore clear that different views on the concept of sustainability should be reviewed to develop the conceptual framework of ERSs. Secondly, the review of ERSs suggested that the allocation of different points to different criteria implies an expression of significance and, hence, weightings are dependent on the understanding of the environmental impacts of constructed items. Although the importance of absolute measures to determine the carrying capacity of the environment is identified, such measures are still not sufficiently available and hence the study has to depend on expert opinion. However, the importance of different environmental impacts in the selected project type in Sri Lanka was analysed. Thirdly, the importance of stakeholder and public participation was identified. Hence, in the application of the conceptual framework to the selected project type, public perception and the opinions of experienced project team members were considered so as to identify the problems and solutions associated with such projects. Finally, an approach closely related to the identified nesting principle was used in the conceptual framework with several hierarchical levels that break down the environmental problems and solutions into several detailed levels.

Chapter 4: Environmental Assessment of Infrastructure Projects

4.1. Introduction

This chapter reviews environmental impacts associated with infrastructure development. Chapter 1 and Chapter 3 pointed out the lack of infrastructure-related ERSs and the importance of type-specific ERSs. This chapter presents ERSs for infrastructure assessment which have been published so far. It reviews four ERSs published for infrastructure assessment and compares their criteria for assessment and the relative weightings assigned in each system for the different criteria.

4.2. Environmental Impacts of Infrastructure Projects

As explained in Chapter 1, in the coming decades, there will be an upsurge in infrastructure development globally. Despite their significance in terms of the socio-economic development of every nation, infrastructure development causes many environmental problems throughout their project life-cycles depending on the type of infrastructure. The OECD (2006) showed that current trends in infrastructure development are likely to see an accentuation of two facets of infrastructure in the coming decades: on the one hand is its ability to resolve some of the major socio-economic needs of countries including those supporting economic growth, meeting basic needs, lifting people out of poverty, and facilitating mobility and social interaction; on the other is the increasing pressure that it would exert on the environment due to adverse environmental impacts associated with infrastructure both at the stage of development and throughout their life-cycle.

For instance, coal-fired and lignite-based thermal power plants cause emissions of GHGs, mainly, carbon dioxide (CO_2), sulphur dioxide (SO_2), nitric oxide (NO) and air-borne inorganic particles such as fly ash, carbonaceous material (soot) and suspended particulate matter (SPM); hydropower and irrigation projects require the construction of huge structures leading to landslides, water pollution and loss of vegetation; diversion of water bodies due to dam projects leads to drought conditions; roads utilize a large proportion of land in many countries and lead to erosion, deforestation, habitat fragmentation and destruction, with negative effects on biodiversity (ECG, 2007; OECD, 2008; WWF, 2013). Many infrastructure projects also have an adverse impact on fauna species because the fragmentation and degradation of the natural landscape and the isolation of habitats create barriers to natural migration and the movement of animal populations (OECD, 2008). OECD (2008) also showed that expansion in infrastructure development is one of the main pressures on biodiversity leading to the extinction of a number of flora and fauna species though there are other reasons for this as well including agriculture and climate change. The OECD (2008) also showed that 32% of future biodiversity loss up to the year 2030 is likely to come from infrastructure development.

Bhattacharya et al. (2012) emphasized that there is a strong need to ensure the environmental sustainability of infrastructure which can play a major role in determining the readiness of our societies and economies to cope with environmental issues. They showed that although sustainable infrastructure investments sometimes attract additional costs upfront, the net economic effect of these additional investments, due to efficiency improvements and wider benefits (including energy security, safety, cleaner methods, guarantees of biodiversity and technological discovery as well as fundamentally reduced climate risk) can be strongly positive.

Impacts of environmental degradation are particularly severe in developing countries since they are the most vulnerable to climate change and tend to be more dependent than advanced economies on the exploitation of natural resources for economic benefits (OECD, 2012). Though most developing countries contribute only minor shares to global GHG emissions today, they are slated to increase their emissions and to increasingly become sources of emissions with current trends in natural resource usage (OECD, 2012) and developmental trends.

4.3. ERSs for Infrastructure Projects

As explained in Chapters 1 and 3, ERSs play an important role in evaluating and measuring the environmental performance of construction projects. Though there are many ERSs for assessing buildings, only a few infrastructure-related ERSs have been published so far. However, with current developmental trends and increased awareness of the environmental impacts of infrastructure development, further attention needs to be paid to infrastructure-related environmental assessment. Therefore, the rest of the chapter discusses existing infrastructure-related ERSs.

4.3.1. CEEQUAL - Civil Engineering Environmental Quality Assessment and Awards Scheme (UK)

CEEQUAL, based in the United Kingdom, is the assessment and awards scheme for improving sustainability in civil engineering projects, which was originally developed and launched in September 2003 by a team led by the Institution of Civil Engineers (ICE), supported by the Institution's Research and Development Enabling Fund and the UK Government. It is now operated, and continues to be developed through CEEQUAL Ltd., owned by a group of fifteen organisations, including the Institution of Civil Engineers (ICE), Association for Consulting and Engineering (ACE) and Civil Engineering Contractors' Association (CECA).

The CEEQUAL Assessment Manual is published to assess roads and railways, airports, coast and river works, water supply and wastewater treatment, power stations, retail and business parks, landscaping, and other public realm works. CEEQUAL is relevant to clients of civil engineering projects, civil engineering design companies and to civil engineering construction companies, including public sector clients, private sector clients, designers, design and build consortia, contractors, funders and regulators of construction schemes (who may want reassurance that projects are carried out in an environmentally responsible way).

The Scheme is available in three forms as follows.

1. CEEQUAL for UK Projects (launched in 2003);
2. CEEQUAL International, for use on projects outside the UK (launched in 2011);
3. CEEQUAL Term Contracts, for use on contracts for maintenance and for multiple small works.

This study refers to CEEQUAL for UK Projects Version 4.1. Under the CEEQUAL assessment scheme, 12 sections are weighted using 200 questions. Figure 4-1 presents the points allocated to each category:

1. Project Management
2. Land Use
3. Landscape
4. Ecology and Biodiversity
5. The Historic Environment
6. Water Resources and the Water Environment
7. Energy and Carbon
8. Material Use
9. Waste Management
10. Transport
11. Effects on Neighbours
12. Relations with the Local Community and Other Stakeholders

The CEEQUAL scheme takes into account environmental, social and cultural issues. The 14% of total points are allocated to social issues under “Effects on Neighbours” and “Relations with the Local Community and Other Stakeholders”. Another 7% has been allocated to “The historic environment”. Except for these two categories and “Project Management”, the balance nine categories include direct physical impacts of infrastructure projects towards achieving environmental sustainability, which accounts for 68% of the total points. Although no direct physical impacts have been included, questions under “Project Management” assess the project team’s commitments that facilitate the environmental sustainability practices of the project.

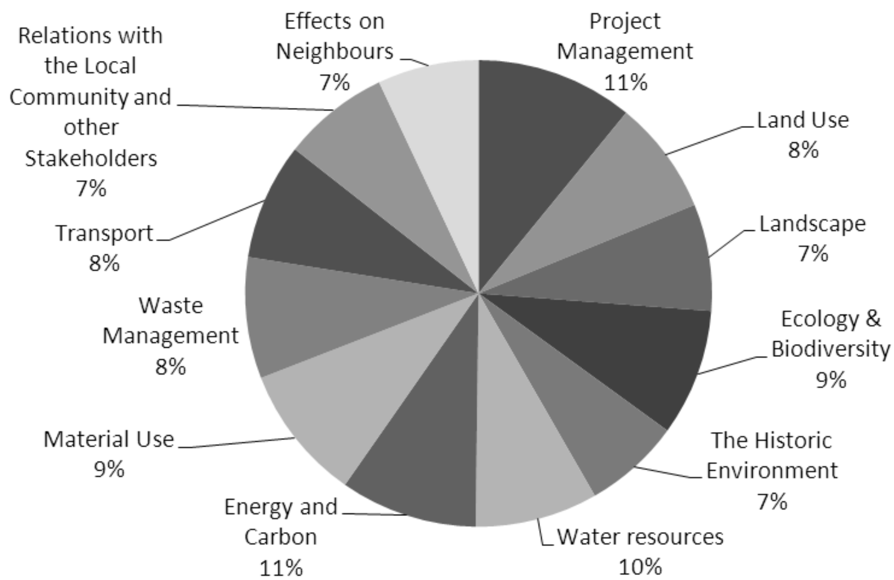

Figure 4-1: Points Allocation of CEEQUAL Scheme

Source: CEEQUAL (2010)

This scheme allows the candidates to score a considerable portion of total points through mere documentation or with meetings and studies. This is because CEEQUAL has introduced different types of awards that facilitate applications by project stakeholders for awards on an individual basis. For example, the client and the designer can score points for including a certain aspect in the brief and in the design respectively. However, actual implementation is not reflected in those questions; it is assessed instead in separate questions. CEEQUAL provides a well-explained manual along with the scheme but sometimes it is overly explained and therefore too lengthy.

4.3.2. BCA Green Mark Scheme for Infrastructure (Singapore)

The BCA Green Mark Scheme for Infrastructure (BCA-GM) is an initiative of the Building and Construction Authority (BCA) in Singapore to promote sustainable development in project planning, conceptualisation, design and specification, and the construction of infrastructure projects with effect from May 2009. The projects are evaluated based on the following five criteria.

1. Landscape, Ecology and Land Efficiency
2. Energy and Renewable Energy
3. Water Efficiency
4. Project Management
5. Waste Management and Environmental Protection

Points allocated to each category are presented in Figure 4-2. In addition, thirty points are allocated under the category of ‘Innovation’.

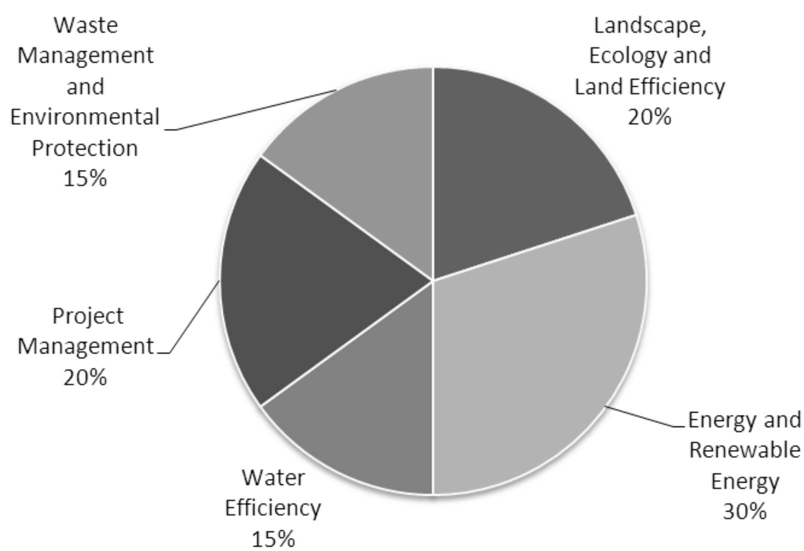

Figure 4-2: Points Allocation of BCA Green Mark Infrastructure Scheme

Source: BCA (2009)

All categories, except for the “Project Management” category, are directly related to the actual physical performance of the project in the achievement of environmental sustainability which accounts for 80% of the total points, with nearly one third of total points allocated to “Energy and Renewable Energy”. This shows that the BCA-GM shows especial concern with energy issues including the generation of renewable energy. Although the criteria under “Project Management,” which accounts for 20% of total points, are not directly related to the actual physical performance of the projects, they too facilitate the sustainability practices of projects.

In addition to the total of 100 points allocated under the five major categories given in Figure 4-2, the BCA-GM awards thirty points under “Innovation” which indicates the encouragement that the Scheme offers to projects which demonstrate more innovative practices with regard to environmental performance. The BCA-GM covers a wide range of environmental issues in a concise manner given that it has only 25 questions. In addition, only a few questions allow for scoring through mere documentation, meetings and assessments while more emphasis is placed on actual physical performance.

4.3.3. IS Rating Scheme - Infrastructure Sustainability Council of Australia (Australia)

The IS rating scheme for infrastructure is developed and administered by the Infrastructure Sustainability Council of Australia (ISCA, 2013). It aims to assess sustainability performance across the four dimensions (the quadruple bottom line), namely, economic, environment, social and governance criteria (Lees, 2013).

The IS rating scheme includes five main categories as follows:

1. Management and Governance
2. Using Resources
3. Emissions, Pollution and Waste
4. Ecology
5. People and Place

Figure 4-3 presents the points allocated for each category. In addition, five extra points are allocated under the category of ‘Innovation’.

One quarter of the total points has been allocated to the category “Emissions, Pollution and Waste” which focuses on minimising the negative impacts of infrastrucutre on ecosystems due to discharges to air, land and water. Another 24% of total points has been allocatd to “Using Resources,” which focuses on energy, water and materials usage. 11% of total points has been allocated to

“Ecology” which focuses on ecologically sensitive areas, ecological value, biodiversity and habitats. 5% of total points has been allocated for “Climate Change Adaptation” though this is listed as a sub-category under “Management and Governance”. These sections, which account for 65% of total points include important factors and assess the direct physical performance of infrastructure projects in achieving environmetnal sustainailbility.

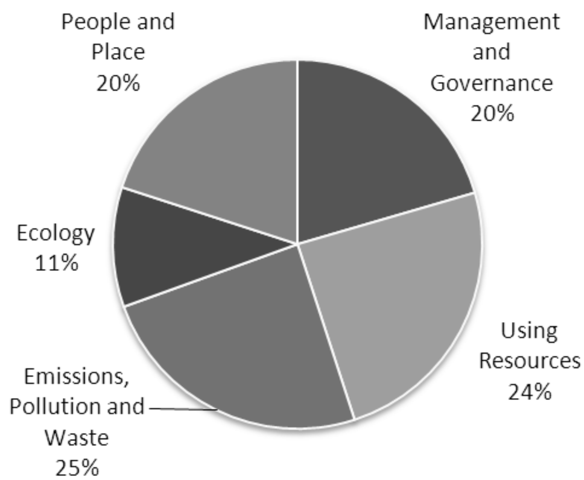

Figure 4-3: Allocation of Credits in IS Rating Scheme

Source: ISCA (2013)

The IS rating scheme focuses on social impacts as well and allocates 20% of total points for “People and Place” which focuses on issues such as health impacts, safety and stakeholder participation. This category also includes 5% of the total points for cultural concerns under “Heritage”. The balance 15% of total points has been allocated to subcategories “Management Systems” and “Procurement” under the main category “Management Systems”. While some of the criteria under these factors do not assess the direct physical impacts on ecosystems or society, they indirectly facilitate sustianatiliby practices.

The IS rating scheme assesses these categories with 52 questions while five additional points have been allocated for ‘Innovation’. The Scheme assesses the performance of projects under three achievement levels with different points allocated for each category under each achievement level.

4.3.4. Envision™ Rating System (US)

The Envision™ Rating System was developed in a joint collaboration between the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure in order to assess infrastructure projects such as roads, bridges, pipelines, railways, airports, dams and water treatment systems as well as other civil engineering projects (ISI, 2012). Firstly, the Zofnass Program for Sustainable Infrastructure was founded in 2008; in 2012, version 2.0 was launched as Envision version 2.0.

While the Zofnass program included four categories, the Envision version 2.0 includes an additional category under 'Leadership', totalling five categories in all. These, along with their subcategories, are given below:

1. Resource Allocation (materials, energy, water)
2. Natural World (site selection, habitat)
3. Climate Change (emissions, climate adaptability)
4. Quality of Life (community, education, values)
5. Leadership (collaboration, management, planning)

Envision version 2.0 assesses projects under five levels of achievement, namely, improved, enhanced, superior, conserving and restorative, while different credits are allocated for achievement at each level under each subcategory. Of these levels, the "improved" level indicates a performance that is above the conventional and that slightly exceeds regulatory requirements while projects reaching the "conserving" level indicate zero negative impacts or "neutral impact" on the environment (ISI, 2012). Achievements of "enhanced" and "superior" levels respectively indicate that projects are on the right track and that they record remarkable performance. The "restorative" level is the highest level, which indicates regenerative effects (ISI, 2012) with regard to the environment. The maximum total credits that can be achieved under each category are presented in Figure 4-4.

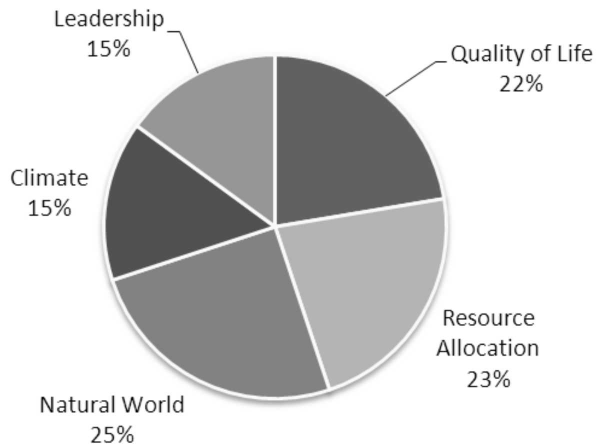

Figure 4-4: Allocation of Credits in the Envision Rating System

Source: ISI (2012)

One quarter of the total credits in this scheme has been allocated to the "Natural World" which focuses on minimising the negative impacts of infrastrucutre on ecosystems through proper site selection, proper land use, avoidance of contamination of land and water and, conservation of biodiversity. Another 23% of the total credits has been allocatd to "Resource Allocation" which focuses on both the efficient use, and reduction in the consumption, of materials, energy and water resources. The 15% of total credits that have been allocated to "Climate" mainly focuses on minimising GHG emissions and other air pollutants, and on promoting climate change adaptability. These sections include importatnt factors for achieving environmetnal sustainailbility of infrastructure projects which account for 63% of the total credits.

In addition, the Envision rating system focuses on social impacts, allocating a considerable amount of credits to these aspects. Thus, 22% of the total credits is allocated for "Qualtiy of Life" which focuses on health impacts, safety and security issues, employment, and other factors for maximising the quality of life of those who use, and are affected by, infrastructure projects. This category also includes 2% of the total credits allocated for preserving historic and cultural resources. The balance 15% of the total credits has been allocated to "Leadership" which includes management practices, collaboration between stakeholders, planning, and compliance with legal requirements in achieving sustainaiblity. While these factors may not have direct physical impacts on ecosystems or society, they indirectly facilitate sustianatiliby practices.

When compared with the earlier Zofnass program, it is evident that Envision version 2.0 offers an improved version in terms of allocation of credits because it assigns a different number of credits to different criteria under each subcategory according to different levels of performance of projects. Another modification has to do with the category of 'Innovation'. While the Zofnass program included separate criteria for 'Innovation' under each subcategory, Envision version 2.0 does not include such criteria for innovation separately. Instead, Envision version 2.0 has addressed innovative practices under different levels of achievement, particularly at the "restorative" level. Thus, it provides a comprehensive set of criteria for the assessment of infrastructure projects in a clear and concise manner and uses 55 questions to assess projects.

4.3.5. Comparison of the Four Rating Systems

A comparison of CEEQUAL, BCA-GM, IS Rating Scheme and Envision Rating System shows that there are common categories in all the schemes along with some categories that are unique to each system. Since the four systems have been developed in different contexts independently of each other, the comparison of weightings is not an easy task. The systems also use different categorisations of criteria which make the comparison even more complicated. Figure 4-5 gives a rough division of points in the four systems into similar categories as a percentage of total points.

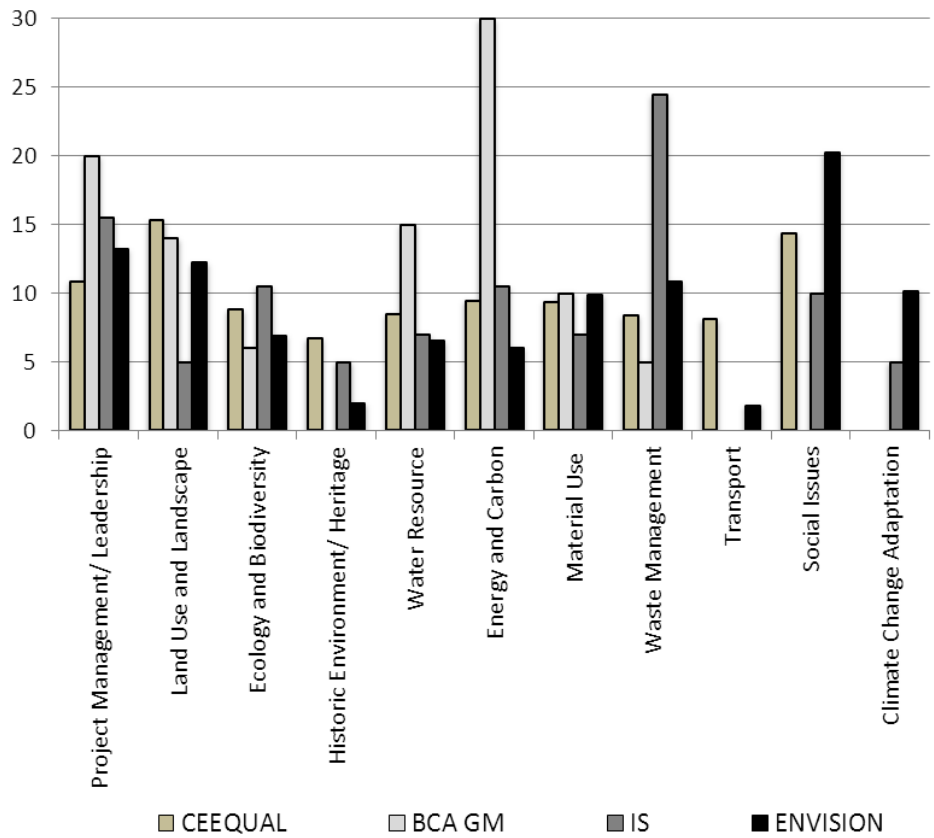

Figure 4-5: Comparison of Allocation of Points (CEEQUAL, BCA-GM, IS and Envision)

Three systems, excluding BCA-GM, allocate points to social and cultural issues though to different extents (10-20% and 2-7% of total points respectively). All four systems, however, have been developed to assess a range of infrastructure project types. Moreover, the categories that relate to environmental sustainability are common to all systems though they may carry different terms. Figure 4-6 offers a comparison of the allocation of points as a percentage of total points among these common categories:

- Project Management/Leadership
- Ecology and Biodiversity
- Resources (Water, Energy, Materials)
- Waste Management.

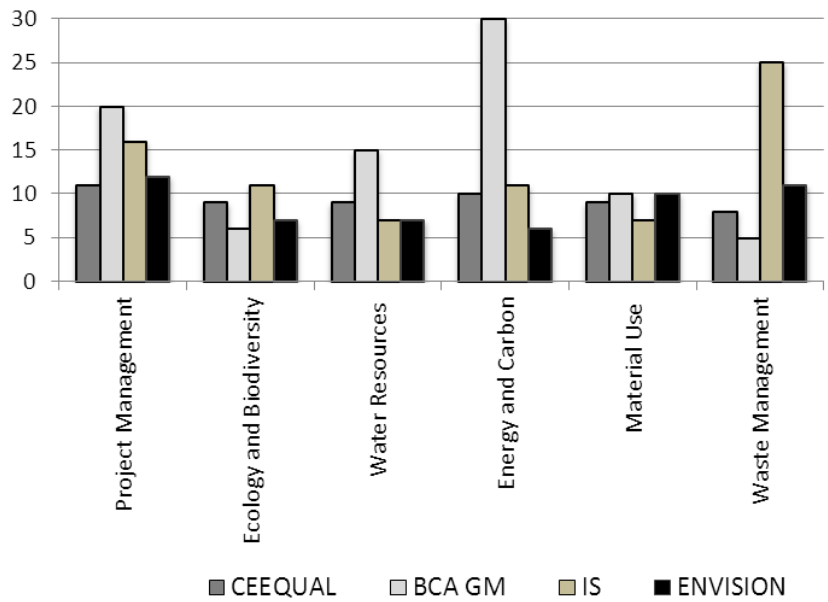

Figure 4-6: Comparison of Common Categories (CEEQUAL, BCA-GM, IS and Envision)

As evident from Figures 4-5 and 4-6, BCA-GM has allocated a majority of points to "Energy and Carbon" which includes 10% of the total points allocated for the use of renewable energy whereas the other three systems have allocated only about 2% of total points for renewable energy. The IS rating scheme, on the other hand, has paid more attention to waste issues compared with the other three systems. In comparison with other categories, ecology and biodiversity has received moderate consideration in all four systems. Though land use has been considered as a major category in three systems with 12-15% of total points allocated, the IS rating scheme has considered this only under "Urban and Landscape Design" in "People and Place". It appears moreover that the IS rating has not considered land efficiency and land use whereas the other systems have paid attention to minimizing land use utilizing different strategies. One reason for this may lie in the fact that, as a country, Australia has not experienced a land shortage so far in relation to infrastructure development. However, despite variations in regional practices, ecology, biodiversity and land use issues are very important factors in infrastructure development and all four rating systems pay varying attention to these aspects.

The IS rating scheme and the Envision rating system explicitly provide different levels of achievement for all the categories. Although in CEEQUAL and BCA-GM, such levels are not explicit for all the criteria, some criteria provide different levels of achievements with different points allocated. Except CEEQUAL, other systems present the assessment criteria in a concise manner but address a wide range of issues. However, CEEQUAL allows clients, designer and contractors to apply for individual awards or combined awards and hence, include many questions to cover performance of these three parties.

4.4. Summary

Though infrastructure development is important for a country's socio-economic progress, infrastructure development has environmental impacts. It is important to consider these consequences, especially in developing countries, which are experiencing increasing demand for infrastructure. ERSs provide an approach to assessing the environmental sustainability of construction projects but only a few infrastructure-related ERSs have been published so far compared to the number of ERSs for assessing the environmental sustainability of buildings. This chapter discussed four existing infrastructure-related ERSs, namely, CEEQUAL in UK, BCA Green Mark in Singapore, IS rating scheme in Australia and Envision rating system in the United States.

Chapter 5: Sri Lanka: Economy, Infrastructure and Power Sector

5.1. Introduction

This chapter provides an overview of key geographical and political information on Sri Lanka, as well as its economy and its infrastructure. Focus is put on the power sector and of the SHP sector in particular, in order to justify the selection of the SHP sector from among the different infrastructure project types in the country for the purpose of applying the proposed conceptual framework for ERSs. The chapter begins with background information on Sri Lanka including the climate, topography and the economy. It highlights the growth of infrastructure development in the country in general. The chapter also provides an overview of the Sri Lankan power sector followed by an introduction to SHP projects and the SHP sector in the country.

5.2. Background Information on Sri Lanka

5.2.1. Geography and Climate

Sri Lanka is an island with a land area of approximately 65,610 square kilometres which lies between 5° 55' and 9° 55' north of the equator and between the eastern longitudes 79° 42' and 81° 52' (GOSL, 2013). Sri Lanka has a population of 20.3 million (as per 2011 estimates) and a population density of 296 people per square kilometre (GOSL, 2013). Due to its location, the climate of the country is characterized as tropical (Department of Meteorology, 2013). However, there are some variations in the climate over time and on the basis of location.

The island consists of mountainous areas in the southern-central part with heights exceeding 2,500 metres, which have a cooler climate with temperatures dropping to 14°C (GOSL, 2013). This central highland contains many complex topographical features such as ridges, peaks, plateaus, basins, valleys and escarpments that strongly affect the spatial patterns of winds, seasonal rainfall, temperature, relative humidity and other climatic elements, particularly during the monsoon season (Department of Meteorology, 2013). The central highland is surrounded by broad plains, leaving the remainder of the country flat, except for several small monolithic hills; the average temperature is 27°C in these low lands (GOSL, 2013).

The rainfall in Sri Lanka has multiple origins such as monsoonal, convectional and expressional rains, which account for a mean annual rainfall that varies from under 900mm in the driest parts (the south-eastern and north-western parts) to over 5000mm in the wettest parts (the western slopes of the central highlands) (Department of Meteorology, 2013). The mean annual temperature varies between 26.5^0C and 28.5^0C in the lowlands, up to an altitude of 100 m to 150 m whereas it is approximately 15.9^0C (at 1800 m sea level) in the central highlands (Department of Meteorology, 2013).

5.2.2. Trends in the Economy

Sri Lanka is mainly an agricultural country where the chief crop is rice (GOSL, 2013). Tea, rubber, coconut and spices are additional important agricultural crops. Fruits and vegetables native to both tropical and temperate regions are also grown in the country (GOSL, 2013). Sri Lanka is a major exporter of precious and semi-precious stones. Remittances from Sri Lankan employees abroad contribute a large share of the nation's annual foreign exchange earnings (GOSL, 2013).

The economic context of the country has changed dramatically in recent years with the end of the Civil War in May 2009 leading to a much improved macroeconomic situation (World Bank, 2013b). The economy grew at a healthy rate of 6.4% in 2012 (Central Bank, 2012). Not only is Sri Lanka now classified as a middle-income country but it has maintained a relatively strong economic growth of over 8% in both 2010 and 2011, posting thus the fastest growth in South Asia in 2011 (World Bank, 2013b). The robust growth for two consecutive years was a result of improved business and consumer confidence and this trend is expected to continue benefitting from improved infrastructure facilities and favourable macroeconomic fundamentals (Central Bank, 2012).

The end of the decades-long Civil War has yielded the following dividends: agricultural land in conflict-affected areas can once again be cultivated; workers no longer have to worry about security restrictions and are able to engage in industries without fear; and domestic consumer and investor confidence has revived in the Sri Lankan economy (World Bank, 2013b). The tourism industry has become one of the fastest growing sectors in the economy, contributing in turn to tourism-related new construction and renovation activities (Central Bank, 2012) due to the rapid increase in tourist arrivals in the country after the end of the war (World Bank, 2013b). Manufacturing, the largest sub-sector within the industry sector, has been rapidly growing offering a wide range of export goods such as petroleum products and leather goods, in addition to readymade garments which sustain the performance of the apparel industry (Central Bank, 2012; GOSL, 2013).

The industry sector grew by 10.3%, contributing substantially to the expansion of the economy in 2012, becoming in fact the main driver of growth. Within the sector, the construction sub-sector has made the most significant contribution recording a growth rate of 21.6% in 2012, which is a significant increase from the 14.2% in 2011, which reflected the massive volume of government-funded development projects as well as the increased construction activities of the private sector (Central Bank, 2012). The increased construction activities have bolstered, in turn, the demand for minerals and construction material as well (Central Bank, 2012).

The infrastructure needs in Sri Lanka, especially in the northern and eastern regions, is higher which is partly the result of reconstruction efforts to repair or rebuild infrastructure damaged or destroyed because of the war and partly the result of diminished access to the region during the war years (Biller and Nabi, 2013). The vision of the political party in power, as articulated in the document titled *"Mahinda Chinthana"* and as reflected in the development plan of the government, promotes national development, growth, and investment (Biller and Nabi, 2013).

5.2.3. Environment and Sustainability

According to the records of the Forest Department (2013) in Sri Lanka, in the 1880s, the forest cover of the country was 84 % of the land area. According to the assessment made in 1999, the country had a total of 1.94 million hectares of forests covering 29.5% of the land area. This figure included 1.47 million hectares (22.4% of the land area) classified as dense forests with the balance 0.47 million hectares (7% of the land area) classified as open forests. In addition, about 90,000 hectares of forest plantations comprised Teak, Mahogany, Eucalyptus, Pine and other local species which accounted for nearly 1% of the land area. Another 20% of the land area is covered with rubber and coconut plantations and other agro-forestry systems such as home gardens (Forest Department, 2013).

There is textual evidence that sustainability was deeply rooted in society as a way of life in ancient Sri Lanka. The unique hydraulic civilization that was in existence in Sri Lanka 1500 years ago attests to this desire on the part of the ancient inhabitants to maintain an ecological balance (Ministry of Environment and Renewable Energy, 2013). However, the gradual shift to a monetized economy and exchange relations which began during the period of European colonialism with the introduction of plantation agriculture has led to the loss of much of the country's inherited natural wealth (Ministry of Environment and Renewable Energy, 2013). Today, the country consequently is faced with numerous environmental problems with environmental degradation identified as a critical national issue (Ministry of Environment and Renewable Energy, 2013). The Ministry of Environment and Renewable Energy has taken initiatives to address these issues and to prioritize environmental protection as an integral part of all development activities.

5.3. The Power Sector in Sri Lanka

Economic growth drives up energy demand, particularly electricity demand (ADB, 2013). The development of the power and energy sector is thus a key aspect of the Sri Lankan government's infrastructure development agenda (BOI, 2013). At present, Sri Lanka is experiencing a significant increase in demand for electricity with a higher rate of annual increase (Rupasinghe and de Silva, 2007; Jerome, 2010) (see Figure 5.1). At the moment, this demand outstrips the supply, and is estimated to rise even more in the near future at an annual pace of 8-10% (Ferdinando and Gunawardana, 2011).

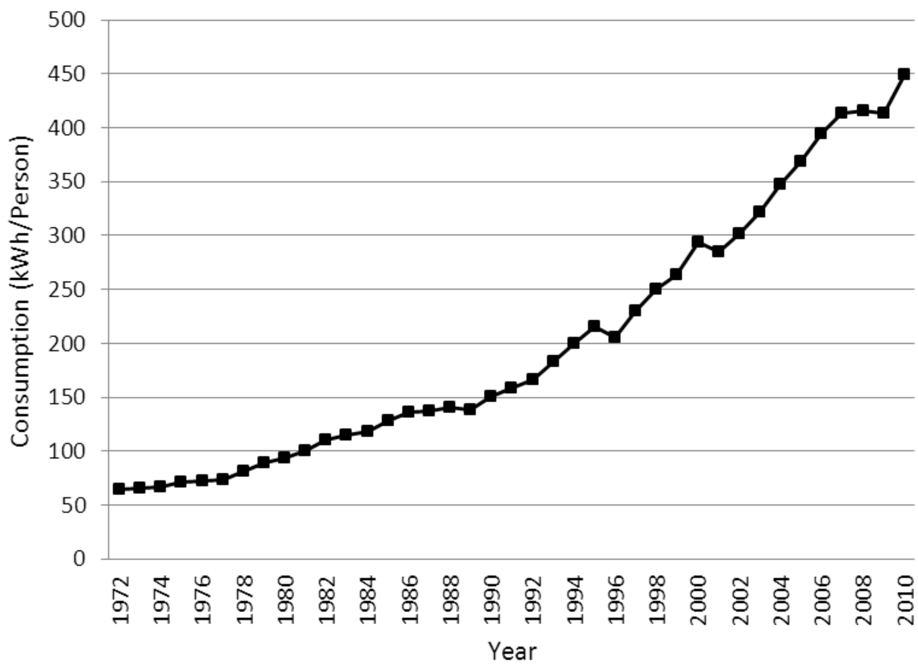

Figure 5-1: Electricity Consumption per capita in Sri Lanka

Sources: CEB (2001 – 2010) and World Bank (2011)

Since Sri Lanka has good hydropower potential due to its geographical configuration that contains a rain-fed central hill zone, the demand for electricity in the past decades was met by hydropower, mainly through large-scale hydropower plants under two main complexes, namely, the Mahaweli Multipurpose Scheme (660MW) and the Kelani Basin System (335MW) (Amarawickrama and Hunt, 2004; Rupasinghe and de Silva, 2007; Ferdinando and Gunawardana, 2011). When the development of hydropower resources commenced in 1950, it focused on generating electricity via conventional hydropower resources. By the end of 2007, a total of 1205 MW of medium and large-scale hydropower generating capacity had been built to supply the national grid (Siyambalapitiya and Wickramasinghe, 2009). Similarly, during the past few decades, national electricity generation has been dominated by hydropower, which accounts for more than 90% of total generation (Ferdinando and Gunawardana, 2011). Indeed, in 1986, the figure was 99.7% (Jerome, 2010). However, hydropower is dependent on the fluctuations in rainfall (Jerome, 2010), with consumers experiencing power cuts during severe drought periods as shown in Figure 5.2. According to Amarawickrama and Hunt (2004), the total estimated hydropower potential of Sri Lanka is around 2000MW. The country's major hydropower potential was almost harnessed (Jerome, 2010) with the commissioning of the Upper Kothmale hydropower project in 2010, totalling an installed capacity of 1,355 MW (Ferdinando and Gunawardana, 2011).

In the recent past, however, electricity generation has been in transition from a predominantly hydroelectric system to a mixed system, with a high contribution of thermal power generation since 1996 (Amarawickrama and Hunt, 2004; Siyambalapitiya and Wickramasinghe, 2009) as shown in Figure 5.2. Further, the importation of oil for power generation is expected to decline over the medium term with a shift to coal power and other alternative sources of energy (Central Bank, 2012). Indeed, the shares of hydropower and oil-fired thermal generations which accounted for 40.2% and 59.8% of energy input to the grid in 2007 have been estimated to reduce to 19.5% and 9.6% respectively with coal-fired thermal generation estimated to reach 70.9% by 2020 (Siyambalapitiya and Wickramasinghe, 2009). Thus the country's electricity generating system may be dominated by coal-fired power in the future which is considered the cheapest alternative to oil-fired generation (Siyambalapitiya and Wickramasinghe, 2009). Coal-based electricity generation has already commenced with the commissioning of the Norochcholai coal power plant (300 MW) in 2010 in the Puttalam District.

However, there is also a trend in the Sri Lankan power sector towards non-conventional renewable energy sources such as wind power, bio-mass power (using agricultural and industrial waste), and solar power. Currently, a wind farm in Hambantota contributes 3MW to the national grid with more wind power projects in Willpita, Mampuri, Vidatamunai and Seguwanthivu being commissioned to contribute 0.15 MW, 10MW, 10MW and 10MW respectively to the grid. In addition, eight more wind power projects have signed Standardized Power Purchase Agreements (SPPAs) with Ceylon Electricity Board (CEB) and are expected to contribute a total capacity of 64.8 MW (CEB, 2011). According to Young (2003), more studies are being implemented to identify sites for wind farms for future development purposes. In the area of bio-mass power, the Tokyo Biomass Power Project and the Badalgama Biomass Power Project, using agricultural and industrial waste power, have been commissioned to contribute 10MW and 1MW respectively to the national grid. A further seven projects utilizing Biomass-Dendro power have signed Standardized Power Purchase Agreements targeting a total capacity of 37.77 MW (CEB, 2011). In addition, solar power projects, with a total capacity of 0.018 MW, have been connected to the national grid and two more projects with a total capacity of 1.237 MW will be commissioned in the near future. However, the total contribution of these renewable energy sources is less than 2% of the total national electricity generation.

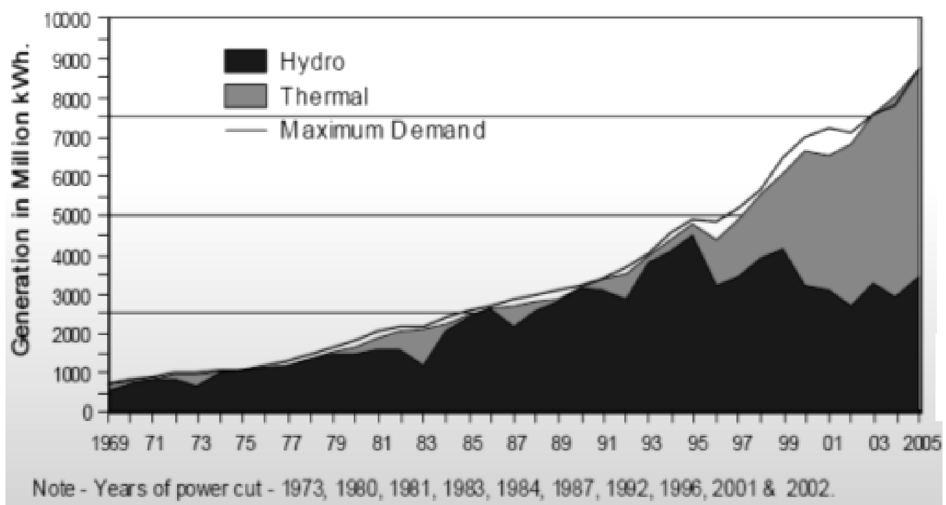

Figure 5-2: Hydro and Thermal Electricity Generation in Sri Lanka, 1969-2005

Source: CEB (2005)

Consequently, the energy sector in Sri Lanka is still dependent on expensive and volatile petroleum imports (Biller and Nabi, 2013) such as fossil fuel and coal which have the potential to plunge the country into acute energy insecurity and directly related issues (Shanthini, 2010). These include the economic drawbacks of higher costs since the country has no domestic production of coal, crude oil, or natural gas, and thus all the fossil fuel demand is met through imports (ADB, 2013). Thus the country's energy generation mix should be diversified to improve efficiency via a mix which includes more renewable energy sources (Biller and Nabi, 2013; ADB, 2013). With this aim in sight, the Sri Lankan government has taken measures to increase investments in SHP generation in order to get the maximum out of the hydropower potential of the county (Rupasinghe and de Silva, 2007).

5.4. The Small Hydropower (SHP) Sector

The SHP sector is the type of infrastructure that the present study has selected in order to apply the proposed conceptual framework for ERSs for assessing environmental sustainability of infrastructure projects in Sri Lanka. An overview of the SHP sector is therefore presented in this section.

5.4.1. Types and Components of SHP Projects

There is no internationally accepted formal definition of SHP generation in place as yet (Abbasi and Abbasi, 2011), hydropower being described as having various degrees of 'smallness' (Paish, 2002). The general practice worldwide therefore is to define SHP generation by power output with several categories defined under SHP projects. Not only do different countries follow different norms but the break points between categories are differently interpreted in different countries (Paish, 2002; Abbasi and Abbasi, 2011).

According to Kaldellis et al. (2005), power stations with rated power up to 10MW, 1MW and 50 kW are characterized as small, mini and micro-hydropower projects respectively. For Abbasi and Abbasi (2011), those with a capacity from 0.1 MW to 2 MW are micro hydropower projects and those between 0.1 MW and 50 MW are mini hydropower projects. In cases, where the power output is less than 5kW, such projects are called 'pica-hydro'. However, this scale is not uniform as some authors put the upper limit of 'pica-hydro' at 20 kW (Abbasi and Abbasi, 2011). Table 5-1 gives the upper limits of power generation capacity set by different countries to define the smallness of their hydropower projects.

Table 5-1: Upper Limits of Power Generation Capacities of SHP Projects Set by Various Countries

Country	**Limit (MW)**	**Source**
UK	<5	Abbasi and Abbasi, 2011
United States	<25	Hennig et al., 2013
Sweden	<15	Abbasi and Abbasi, 2011
Colombia	<20	Abbasi and Abbasi, 2011
Australia	<20	Abbasi and Abbasi, 2011
India	<_25	Abbasi and Abbasi, 2011; Hennig et al., 2013
China	<50	Hennig et al., 2013
The Philippines	<50	Abbasi and Abbasi, 2011
New Zealand	<50	Abbasi and Abbasi, 2011

SHP projects can be of two types: the run-of-river type, which is constructed mostly with low diversion structures, often a small dam or a weir, and the storage type (Pinho et al., 2007). Run-of-river plants make use of the natural flow of water in streams and rivers creating pressure that spins the turbines to produce electrical energy and thus is dependent on seasonal runoff patterns (IEA, 2002; Jerome, 2010). This is the more common type of SHP and basically uses the river flow as it occurs throughout the day and throughout the year, whereas the second type creates a reservoir to store flowing water to be used later (Pinho et al., 2007).

A traditional SHP plant integrates the following structures as shown in Figure 5-3: the water diversion circuit including the headrace channel (an open channel or tunnel), a forebay tank, and the penstock which makes the connection between water intake and powerhouse; the powerhouse, where the potential energy of the water is converted into electricity, by means of turbines and generators; and a tailrace channel (or tunnel), returning diverted water to the river (Pinho et al., 2007). But, as pointed out by Pinho et al. (2007), the total area affected by a SHP project may spread well beyond the areas occupied by these structures. The stretch of the river between the dam/weir and the end of the tailrace channel, the affected downstream, and some adjoining lands that are used for the substation, transmission lines and the access roads to the power plant site are also among the areas affected by the setting up and operation of a SHP project.

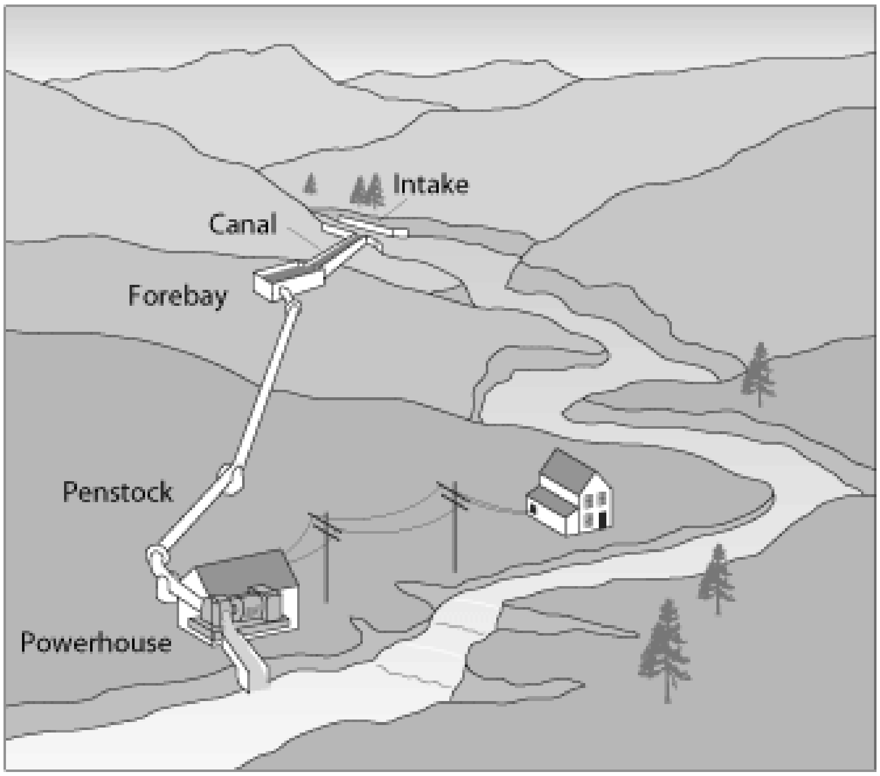

Figure 5-3: Major Components of a Typical SHP Project

5.4.2. Global Increase in Interest in SHP Projects

SHP technology is not new, being a type of power generation that humankind has been using for centuries throughout the world in the form of watermill hydropower (Abbasi and Abbasi, 2011). However, it was the invention of the water turbine in France in 1827 which led to the development of modern hydropower generation (Abbasi and Abbasi, 2011).

Many developing countries are facing an energy crisis due to the increase in industrialization for various development programs (Sharma et al., 2013). If the increasing demand for power is to be supplied via thermal power plants, it will cause environmental problems in addition to the high cost of generation. Hence, there is an increasing need to diversify the energy mix of countries where thermal power dominates power generation (Hennig et al., 2013). This trend has placed renewable energy, mainly SHP, in a foremost position as a desirable form of non-conventional power (Hennig et al., 2013). Both the increase in the electricity requirement globally and renewed interest in renewable energy sources have rendered SHP development a subject of great interest worldwide (Kumar and Verma, 2007).

The global installed capacity for electrical power generation via SHP was 32GW in 2000 (Bakis, 2007). The total installed capacity of SHP projects was approximately 47GW in 2007. Europe, with about 13GW of this installed capacity, was the second biggest user of SHP just behind Asia (Abbasi and Abbasi, 2011). In China, SHP is the major backbone of rural electrification and it supplies more than 97% of the country's renewable electricity (Hennig et al., 2013). India's installed SHP capacity of 3,434MW at the end of August 2012 contributed about 13.2% of the total grid interactive renewable power generation (Sharma et al., 2013).

Not only have many countries acquired increased capacities for power generation via SHP generation but they have also identified greater potential to develop SHP projects further in their countries. For example, in India, a total of 5,403 potential sites for SHP projects have been identified so far with an aggregate estimated capacity of 14,294 MW (Kumar and Verma, 2007). The strategy of the Ministry of New Renewable Energy in India (MNRE) is to promote the maximum utilization of SHP and to increase the share of renewable energy in the Indian power sector (Sharma et al., 2013). China, already a significant user of SHP, has plans for more SHP projects. In Indonesia and Bangladesh, the estimated capacities are 500MW and 10,000MWh respectively but only 5MW have so far been installed and just 1MW is being actually used in Indonesia while Bangladesh has almost zero utilization (Abbasi and Abbasi, 2011; Razan et al., 2012).

While estimates may vary, there is no argument therefore about the fact that the world at present is utilizing only a very small fraction of the SHP potential. Though Asia leads the world as the biggest SHP generating continent, it yet shows an underutilization of this resource (Abbasi and Abbasi, 2011). It is therefore logical to expect many more SHP projects to be implemented in the coming years in many countries with good hydropower potential.

SHP plants are usually regarded as clean technology for the production of electricity since it emits a very low level of GHG compared to fossil fuels (Pinho et al., 2007; Sharma et al., 2013). However, the negative consequences of SHP projects are not negligible due to increasing developmental trends in the sector and their cumulative implications on environmental sustainability (Hennig et al., 2013).

5.4.3. SHP Sector in Sri Lanka

The history of SHP generation in Sri Lanka spans over a century where SHP plants were first set up in large-scale tea plantations in the central hilly regions and used by colonial planters as the predominant source of power for their plantation needs (Thoradeniya et al., 2007). In 1990, micro hydropower plants were built for village electrification with a typical plant built across a stream to produce 2 to 10 kW of power (Thoradeniya et al., 2007).

SHP plants were connected to the national grid for the first time on 30th of April 1996, with a total capacity of 0.96 MW (Rupasinghe and de Silva, 2007; DFCC, 2007; CEB, 2011). Currently, Standardized Power Purchase Agreements are offered to private entrepreneurs to build power plants with a capacity less than 10 MW under the procedure for electricity purchases from small power producers (SPPs) by the Ceylon Electricity Board (CEB, 2011). Currently 119 SHP projects have been connected to the national grid with a generation capacity of approximately 255 MW as of August 2013 (CEB, 2013).

The economically feasible SHP potential in Sri Lanka is estimated to be 400 MW (SEA, 2013). Hence, more SHP projects will be implemented in the country in the near future. These projects will be supported with long term strategies that have been introduced with the active participation of the private sector, which plays a key role in the country's power and energy sector (BOI, 2013).

5.5. Environmental Assessment of Infrastructure in Sri Lanka

In 2011, the Green Building Council of Sri Lanka (GBCSL) launched the Green Rating System for Built Environment. Although the green building concept is quite new to Sri Lanka, GBCSL (2011) showed that public perception of the importance of sustainable green designs is increasing followed by a great level of demand.

However, the assessment of infrastructure for environmental sustainability is still limited to the EIA and Initial Environmental Examinations (IEE). And even this process has been criticized for its many shortcomings (Zubair, 2001; Kodituwakku, 2004; Samarakoon, 2008), among which the limiting of the process to only certain prescribed projects and the ineffectiveness of post-EIA monitoring are the most important. EIA process is mandated only for large scale development projects or projects which are located in environmental sensitive areas (CEA, 2013). The types of projects which require EIA have been prescribed in the Gazette No. 772/22 of 24.06.1993 under the Amendment Act to the National Environmental Act, No.47 of 1980 including large scale construction projects and industrial activities which involve chemical processes.

With regard to SHP projects and projects located in ecologically sensitive areas, those that clear of land areas exceeding 50 hectares, convert forests covering an area exceeding 1 hectare into non-forest uses, and all renewable energy based electricity generating stations exceeding 50 MW are prescribed to carry out the EIA procedure. Therefore some SHP projects are not subjected to these assessment procedures due to their small scale.

5.6. Summary

This chapter presented some background information on Sri Lanka including its geography, climate and economy. Rapid economic growth in the country in the post-Civil War period in particular increases the demand for electricity. Country's electricity generation is in transition from a hydropower dominated sector to a thermal power dominated one. However, due to the economic drawbacks and environmental problems associated with thermal power generation, the government has taken measures to increase electricity generation through non-conventional renewable sources. SHP generation plays an important role here by generating the largest share of renewable power generation in the country. There is an increasing global interest in SHP generation recently due to its many economic benefits and the belief that it is environmentally friendly. However, SHP projects are not without environmental problems unless they are designed and managed carefully. Motivated by this context, the study selected the SHP sector in order to demonstrate the application of the proposed conceptual framework for developing type-specific ERSs in the infrastructure sector in Sri Lanka.

Chapter 6: Conceptual Framework and Hypothesis

6.1. Introduction

This chapter reviews the concept of sustainable development in order to establish the theoretical underpinning of ERSs. Section 3.7.3 highlighted an emerging trend to take into consideration a wide range of sustainability aspects in ERSs in construction, but showed that there is little agreement on what aspects to be used or which view of sustainability to be followed. This chapter discusses the dominant views of sustainable development and presents a detailed discussion of the concepts of Environmental Economics in order to emphasize the role of the natural environment in sustainability. It will then identify the factors which are important in achieving environmental sustainability in infrastructure projects and present the hypothesis of the study.

6.2. The Concept of Sustainable Development

6.2.1 The Term 'Sustainable Development'

Not only has 'Sustainable Development' been defined in many ways (IISD, 2013; World Bank, 2001), the term and its definition have been debated over many decades (Redclift, 2005; Halla et al., 2005). To this day, it remains a contested concept with no clear agreement on what the term means (Barraclough, 2001; Chatterton and Style, 2001) with diverse groups putting their own interpretations on its meaning (Giddings et al., 2002) leading to a spectrum of views (Turner, 1993; Klostermann and Cramer, 2006; Brandon and Lombardi, 2011). For example, on one side of the spectrum, ecologists hold on to the eco-centric view that is classified under Very Strong Sustainability (VSS) which nearly rejects even the sustainable utilization of nature's assets (Turner, 1993). Another view holds that conservation should be undertaken at all costs, along with a change in life styles and a reduction in economic growth as means to reduce consumption (Brandon and Lombardi, 2011). Yet another view in the spectrum subscribes to the belief that a 'technical fix' should be invented to remove the need for such drastic changes

(Brandon and Lombardi, 2011). Many neo-classical economists hold the techno-centric view which can be classified under Very Weak Sustainability (VWS) (Turner, 1993). Therefore, although different parties propose different principles for achieving sustainability, there is no universal agreement on or acceptance of them. Nor are they universally established (Dasgupta and Tam, 2005).

Many assert that the term "Sustainable Development" came into use and gained increasing popularity after the publication of "Our Common Future": the report of the World Commission on Environment and Development (WCED) (Brundtland Commission) in 1987 while the definition introduced there is widely invoked (Barraclough, 2001; Redclift, 2005; Hanley *et al*., 2001; Ugwu and Haupt, 2007). The Brundtland report defined 'Sustainable Development' as,

> *"The development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED, 1987)*

However, this definition has been criticised and questioned on several fronts.

6.2.2 What are the 'Needs' to be addressed?

As also explained in the Brundtland report, the discussions on 'needs' contain the issue of how to define the needs of diverse groups (between different cultures and between developing and developed countries) (Redclift, 2005) and how to know the needs of future generations today (Halla et al., 2005). For example, while fresh air and open spaces are scarce for one part of the world, another community is striving for more material wealth, even at the cost of increased environmental pollution, a situation which is apparent in developing countries (Redclift, 2005). Similarly, people have conflicting needs (World Bank, 2001). As Brandon and Lombardi (2011) pointed out, the definition provided in the Brundtland report has been criticised because it is difficult even after decades to determine people's needs.

However, the report also stated that “needs” are the essential needs of world’s poor (food, clothing, shelter, jobs) and that these should be given priority. It explained furthermore that while interpretations of “needs” may vary among people from different parts of the world, they would share some common features. Sustainable development requires the basic needs of all to be met and for all to satisfy aspirations towards an improved quality of life within the bounds of the ecological possible (WCED, 1987). At Rio+20, the United Nations Conference on Sustainable Development, it has been agreed that eradicating poverty an indispensable requirement in sustainable development and is the greatest global challenge facing the world today (UNCSD, 2012).

6.2.3 The Term “Development”

The term “development” has also generated debates regarding the level and the type of development required by different social actors in different parts of the world. This is because development, in terms of economic, social, cultural and political, is not similar (Barraclough, 2001). This is why the term ‘development’ often requires an adjective (Goodland and Daly, 1996) without which it becomes vague. Consequently, ways of measuring ‘development’ are also debatable.

Three distinct development processes are usually explained under sustainable development; economic development, community development and ecological development (ICLEI, 1996). Each of these three processes has its own imperatives which display contradictions in relation to each other (ICLEI, 1996). For example, the externalization of costs in order to maintain the rates of private profit can contradict the ecological imperatives to value and conserve natural resources. Moreover, the global expansion of markets and the integration of national economies through structural adjustment programs and free-trade agreements can undermine community development imperatives of local self-reliance and the meeting of basic human needs (ICLEI, 1996).

Taking into consideration these concerns, sustainable development has been defined and presented as containing three inter-connected sectors; economy, environment and society, which in Figure 6.1 are presented as three interconnected rings. However, this ring model has been criticised on several fronts. Giddings et al. (2002) argued that this model shows three equal-sized rings in a symmetrical interconnection and encourages the assumption of separation and even autonomy of the three sectors. Researchers showed that this compartmentalization can lead to the assumptions of possible trade-offs between three sectors, in line with the view of weak sustainability (Neumayer 2003; IUCN, 2006). They also argued that this narrow techno-scientific view allows for the seeking of technical methods to solve environmental problems but that it does not enable one to see the connections between the three sectors, thereby failing to tackle the root causes of environmental problems (Neumayer 2003; Giddings et al., 2002; IUCN, 2006). They moreover showed that this view has given rise to bias on the part of policy makers towards economic growth at the expense of the other compartments: environment and society (Neumayer 2003; IUCN, 2006).

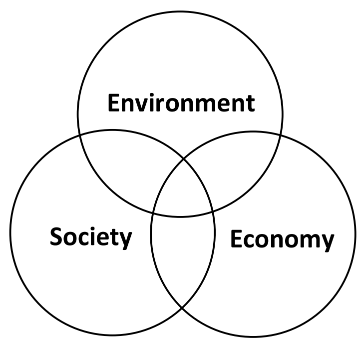

Figure 6-1: Ring Model

Source: Giddings et al. (2002)

Another issue stemming from this view was to see sustainable development as bringing the three sectors together in a balanced way. Young (1997) described 'sustainability balance' as a three-legged stool, with a leg each representing the ecosystem, economy and society.

However, based on the early criticisms, there was a need for a paradigm shift in identifying the relationships between the three sectors where both the economic system and society are constrained by environmental limits (Ott, 2003). Similarly, Neumayer (2003) and IUCN (2006) argued that in the ring model, the environment was seen as equal to society and the economy whereas the economy was dependent on society and the environment, while human existence and society are not only dependent on but are bound by the limits of the carrying capacity of the environment. Economic and social development endeavours must therefore be nested within these limits (Ndah, 2013). In recognition of this reality, the ‘Nested Model’ (Figure 6.2) was presented as a corrective model to the ‘Ring Model’ (Giddings et al., 2002).

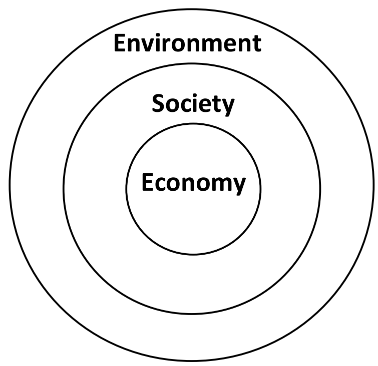

Figure 6-2: Nested Model

Source: Giddings et al. (2002)

The nested model represents the gradual realization that sustainable development embodies integration, understanding, and acting on the complex interconnections that exist between the environment, economy, and society. It also shows that the relationship between the three is not a balancing act or a playing off of one issue against the other, but the recognition of the interdependent nature of these three pillars (Drexhage and Murphy, 2010).

6.2.4 ‘What is to be sustained?’

‘What is to be sustained?’ is another issue in the debate on sustainable development. While Environmental Economists argue that the natural stock of resources (critical natural capital) should be sustained (Redclift, 2005), Thampapillai (2002) pointed out that the natural environment is the core of any economy and that economies cannot be sustained without a natural environment and that, therefore, environmental sustainability is a necessary condition for economic sustainability.

However, as Giddings et al. (2002) pointed out, this position was not appreciated by many groups. Thus economic systems continued to dominate the natural environment and the society, primacy being given to economic growth. However, with the increasing environmental problems the world is facing today, there is more recognition of the role of the natural environment in the sustainable development paradigm.

At Rio+20, it was recognized that natural resources and ecosystems provide the base for and support economic, social and human development and that protecting and managing this natural resource base are therefore the overarching objectives of, and essential requirements for, sustainable development (UNCSD, 2012). Moreover, the emerging concept of a 'green economy' entails recognition that decades of creating new wealth through a 'brown economy' model have not substantially addressed social marginalisation, environmental degradation and resource depletion and that therefore the time has come to understand the linkages between the concept of a 'green economy' and sustainable development (UNEP, 2011).

6.3. The Role of the Natural Environment

The previous sections of the chapter have underscored the significant role of the natural environment in ensuring human well-being and continuous economic growth. The concept of sustainable development highlights the fact that the natural environment should be sustained for everything else to be sustained. Therefore, it is necessary to study the relationship between the economic system and the natural environment. The next section reviews the way the natural environment has been comprehended in the study of Economics throughout the subject's history, an understanding that has undergone revision over time (van den Bergh, 1996, p.11).

6.3.1 Evolution of the Role of the Natural Environment in Economics

In early human history, when society was based on agriculture, the role of the natural environment was seen as a source for the supply of inputs, especially, land and water (van den Bergh, 1996, p.11) for agriculture. Increased awareness of and attention to the role of the environment (Thampapillai, 2002) emerge as people begin to experience environmental degradation in terms of pollution and resource scarcity due both to economic growth and population growth. Daly (1994, p.22) explained this through the notion of moving from an empty world to a full world: a world relatively full of human beings and their artefacts, a notion that Boulding (1966) had first proposed in his paper, "*The Economics of the coming spaceship earth*".

While some were emphasising the environmental limits on economic systems, another group was emphasising the role of technology in expanding these limits which sometimes undermined the notion of environmental limits. According to Turner et al. (1994, p.1), although only a minority comprised the former group in comparison with their contemporaries in the latter, the message of the former is more relevant today than ever before. Several major standpoints on these different views can be found in classical economics and neoclassical economics, with classical economists being those who explicitly identified the environmental limits on the economy and neoclassical economists being those who overestimated the role of technology.

The origin of Economics as a distinct field of study is traced to 1776 when Adam Smith (1723-1790) published *The Wealth of Nations* (Common and Stagl, 2005). Although Smith expressed optimism regarding the availability of natural resources due both to the opportunities for expansion afforded by colonialism and the socio-economic, scientific and technological changes that took place around this time and which either coincided with or were made possible by the Industrial Revolution, with the price increases in agricultural products around the 1800s, economic theorists became more pessimistic about the future limits to production and natural resource availability (van den Bergh, 1996, p12). This pessimism was reflected in the land rent theory of David Ricardo (van den Bergh, 1996) and the population theory of Thomas Robert Malthus (1766-1834) whose theory represented the most pronounced classical perspective on absolute scarcity (van den Bergh, 1996). Malthus' theory denoted the limits to economic growth due to the finite physical limits set by the natural environment (van den Bergh, 1996), which was based on the assumed fixed supply of agricultural land and the propensity of human populations to grow in size (Common and Stagl, 2005).

Classical economists' views are important in the history of Environmental Economics because they recognized the constraints posed by environmental limits to economic activities in the long term, especially on population growth and resource-based sectors and therefore offered integrated views (van den Bergh, 1996; Thampapillai, 2002). However, classical economists also dealt with environmental and resource issues in various ways (van den Bergh, 1996). Classical economics is also widely known as 'the dismal science' because it took up the position that the long-term prospects for improving living standards were poor, a view which is particularly associated with Malthus. Classical economists are also considered as those who set limits to the expansion of economic activities, so that in the long-run it would have the effect of driving down the wages of workers to subsistence levels (Common and Stagl, 2005).

However, the pessimism expressed by classical economists over natural limits was overlooked while optimistic models came to be widely accepted and had the upper hand in the environmental debate for many years thereafter (Thampapillai, 2002). Moreover, the models presented by the Malthusian school had some mathematical inconsistencies which made the models and their results less credible and less accepted. Thampapillai (2002) saw this as one important reason for the demise of pessimism and the wide acceptance of optimistic models.

Common and Stagl (2005) saw the experiences of economies which enjoyed rising living standards despite continuous growth of population as one reason for this demise; moreover, what Malthus had overlooked in proposing his theory was the role of technological progress (Hanley et al. (2001, p.125). However, it should be noted that during this period of high population growth and rising living standards, the people in Western Europe and their offshoots did not have to depend on a fixed supply of agricultural land; because, food was being imported increasingly into Western economies from other geographical areas (Common and Stagl, 2005). However, environmental limits should be considered for the planet as a whole rather than regionally in order to understand the real situation. Nevertheless, upholding the contrary view, neoclassical economists entertain optimism regarding the natural limits to economic activities. As a result, for over three decades after the Second World War, the singular emphasis was on economic growth while environmental limits on economic growth came to be underrated (Thampapillai, 2002).

According to Common and Stagl (2005), it was due to this emphasis that mainstream economics gradually began to evolve into neoclassical economics and, in turn, became the most influential economic perspective (van den Bergh, 1996). However, it does not mean that all neoclassical economists ignored the importance of the natural environment because reputed neoclassical economist Alfred Marshall (1891), who is considered as the founder of modern neoclassical economics, recognised nature and natural resources as the ultimate factors of production. He stated that "Man does not create things. He only rearranges matter," which implied that economic entities (firms and households) are not able to continue production without natural endowments and thus depend on the natural environment (Thampapillai, 2002). At the same time, Irving Fisher laid the foundations of capital theory and attributed three properties to capital which interpreted the use of the natural environment as follows: durability *(if we do not interfere, nature remains intact);* provision of flow of services *(air to breathe, water to drink, soil to till);* and depreciation with usage *(environmental degradation)* (Thampapillai, 2002).

However, the neo-classical economic theories which developed thereafter explained economic growth in terms of savings, investment, capital accumulation, labour productivity and substitutability between labour and capital (Thampapillai, 2002) while largely ignoring the relationships between human housekeeping (economy) and nature's housekeeping (ecology) (Common and Stagl, 2005). By the 1950s, therefore, the ideas of classical economists were taught only as part of economics history while the singular emphasis was on economic growth. In this era, theories of economic growth came to be developed in which the natural environment did not figure (Common and Stagl, 2005). For instance, the Harrod–Domar growth model explained the rate of economic growth in terms of the rate of savings and capital-output ratio while the Solow–Samuelson growth model explained economic growth in terms of capital accumulation. Although the growth models by Solow (1974), Dasgupta and Heal (1979), and Maler (1974) acknowledged the role of natural resources, they showed the substitutability between natural resources and labour capital composite (Thampapillai, 2002) while overestimating the role of new knowledge and technology. Consequently, the production function defined output as a function of labour and capital with the natural environment as a given constant (Thampapillai, 2002). Moreover, neoclassical economists emphasized relative scarcity rather than absolute scarcity (van den Bergh, 1996) and they supported this optimism with several studies.

Scarcity and Growth by Barnett and Morse (1963) was the first systematic empirical examination of historical trends which examined scarcity hypotheses for a variety of natural resources over the period 1870–1958 (Thampapillai, 2002; Krautkraemer, 2005). Except for forests, this time series indexes of resource scarcity showed both upward and downward fluctuations though with a clear downward trend which substantiated the view of decreasing rather than increasing scarcity where resource scarcity is measured in terms of the cost of labour and capital per unit of output (Thampapillai, 2002; Krautkraemer, 2005). Sinden (1972 cited in Thampapillai, 2002) showed similar findings.

Similarly, a study on the declining price trend of minerals over a 70-year period and a study of nonferrous metals over a 90-year period by Nordhaus (1973) and World Bank (1992), respectively, substantiated the notion of declining scarcity and increasingly abundant resources mainly through new knowledge and innovations which thereby enable the discovery of abundant natural resources (Thampapillai, 2002). However, it should be noted that the main weakness here is that these costs do not include the value of natural resources or the after-effects of their extraction but only the cost of labour and capital involved in the extraction (Thampapillai, 2002; Krautkraemer, 2005).

In reality, the declining trend in prices was more a consequence of technological advances in extracting methods and the purchasing behaviour of industrialised countries than confirmation of inexhaustible or unlimited natural resources (Thampapillai, 2002).

It is with the rise in environmental problems locally as well as globally that the need to move towards economics which identified the importance of the role of the natural environment has emerged. Moreover, the industrial revolution has drawn attention to both the physical limits of resources as well as environmental problems (van den Bergh, 1996). Environmental Economics and Ecological Economics thus emerged as disciplines that acknowledge the important role played by the natural environment in the survival of economies and humankind.

Venkatachalam (2007) provided a discussion of the divergences and convergences of the two disciplines. Both Environmental Economics and Ecological Economics share the common objective of understanding the human–economy–environment interaction in order to redirect the economies towards sustainability. However, there are several stretches of Environmental Economics that continue the neoclassical tradition, 'sustainable development' being one of them. This continuation of neoclassical thought can be seen as one of the reasons why the concept of sustainable development entails a balance between the three sectors rather than focusing on environmental sustainability which is the ultimate requirement for the attainment of sustainable development. The primary role of the natural environment and the need to achieve environmental sustainability for the purpose of sustaining all other things is more acknowledged in Ecological Economics. Environmental Economists emphasised the importance of the natural environment for the existence of the economic system and human kind based on the application of thermodynamics laws, which is discussed hereafter.

6.3.2 Thermodynamics Laws in Economics

The initiators of Ecological Economics shared the basic view that the economy and ecological systems are much more intertwined than is usually recognized (Ropke, 2005). Inspired by thermodynamics, systems ecologists developed a new perspective where ecosystem processes were described in terms of flows of energy and matter while some of them began to apply this to the economy underlining how the economy is embedded in nature and how economic processes can also be conceptualized as natural processes (Ropke, 2005).

Ayres et al. (1979) pointed out the applicability of the first law of thermodynamics, also known as the *law of conservation of matter*, to the economic system (van den Bergh, 1996; Hanley et al., 2001). It states that energy may be transformed from one form to another, but that it can neither be created nor destroyed, and that there is a corresponding conservation law for matter: matter can neither be created nor destroyed (van den Bergh, 1996; Common and Stagl, 2005).

According to Thampapillai (2002), the direct implication of this law for the economy is the equality of the sum of material that enters the economy from the environment as resource flows to the sum of the material retained in the economy plus the sum of the residuals (wastes and pollutants) returned to the environment. This law shows that waste will accumulate in the environment and will prevent the environment from performing its functions which would then threaten the natural environment (Hanley et al., 2001) and in turn the economy preventing it from receiving goods and services from the environment consequently. The difficulty and the danger of economic consequences are better explained by the second law of thermodynamics or the *entropy law*.

Georgescu-Roegen (1971) and Daly (1973) have been among the pioneers who understood the importance of the second law, which is also known as ‘the entropy law,’ in relation to the economy (van den Bergh, 1996; Hanley et al., 2001; Thampapillai, 2002). ‘Entropy’ is a measure of the disorder in a system (Ciegis and Ciegis, 2008), which is defined as energy that is incapable of performing work and is thus considered as unavailable (van den Bergh, 1996). The ‘entropy law’ states that the entropy of an isolated system cannot decrease where the energy of the system does not lose energy in terms of quantity, but only in terms of the quality of energy conserved (Common and Stagl, 2005; Raine et al., 2006). In a closed system, where no energy or matter is exchanged with what is outside the system, this entropy process is irreversible (van den Bergh, 1996; Turner, 1993; Thampapillai, 2002).

To apply this to the economy, economic production is entirely dependent on the availability of the low-entropy inputs of natural resources (Daly and Cobb, 1989). Materials enter into economic processes in a usable low entropic status but during their usage they are transformed into and leave in less useful high entropic states such as low temperature heat emissions, exhaust gases and solid waste (Turner, 1993; Turner et al., 1994; Thampapillai, 2002). This process occurs moreover only from low entropy to high entropy but not vice versa. Hence, no material recycling process is 100% efficient (Turner et al., 1994) and the energy and materials available to the economic system for its use will gradually become less (Turner et al., 1994). As a materially closed system and due to the limited solar energy received from the sun, the ability of the natural environment to provide goods and services to the economic system is gradually restricted.

This application of the laws of thermodynamics into the economic system has not been without criticism. Young (1991) argued that the concept of materials entropy is highly problematic since materials entropy cannot be defined independently of technology where, even in a closed system, resource availability may actually increase rather than decrease as a consequence of innovations and technological improvements. A similar argument was raised by Raine et al. (2006) who highlighted the role of “new knowledge” in the development of economic systems. However, in a physical context, the innovation of new stocks of resources which were not available earlier does not mean that dissipated materials which were transformed into high entropic conditions can be recycled back into the economic system. If a new stock is not invented, it is not available at all. Therefore, the application of the concept of, the laws of thermodynamics into the economic system is not inaccurate.

Young (1991) raised another argument: that is, that the earth is not closed with respect to energy because the earth is open to the receipt of solar energy flows

(Townsend, 1992). However, this flow rate is strictly limited due to the amount of solar energy absorbed within a certain period of time and the time taken to convert it into usable energy (Daly, 1992). In the context of natural resource scarcity in economics, the materials flow between the earth and outer space is also negligible (Daly, 1992). The application of entropy to matter as an analogy is also criticised but, as Daly (1992) stated, physicists apply entropy to matter and, therefore, it is far more than a mere analogy.

6.3.3 Circular Flow Model of Economic System

The collective application of the law of conservation and the entropy law to the economic system directed the understanding of the consequences of impacts of economic activities on the natural environment. It also showed how environmental quality impacts on the efficient working of the economy in the reverse direction (Turner et al., 1994).

This understanding gave rise to the opposition of Environmental Economists to the standard circular model of economy which does not include the role of the natural environment (Daly, 1994; Thampapillai, 2002). The circular model of the economy is shown in Figure 6-3 and it is the simplest form of the standard model of the economy which explains the linkages between households and firms (Macdonald, 1999; Jain and Khanna, 2007; Nadar and Vijayan, 2009; Dwivedi, 2010). Households are the owners of labour and capital and also the units of consumption which demand goods and services by firms through spending their income. The firms supply goods and services and are the units of production, which thus demand labour and capital from households through paying them wages and rents. Hence, two types of exchanges occur in this simple system.

But extended forms of the standard model include a set of leakages and injections by recognising financial, government and overseas sectors. At the macroeconomic level, equilibrium is defined by the equality between the sum of all expenditures on final goods and services (aggregate demand) and the sum of all wages and rents (aggregate output or income). However, in this model, the goods and services provided by the natural environment are not discussed. Environmental Economists criticised this standard model of the economic system for its non-recognition of the supporting role of the natural environment within it.

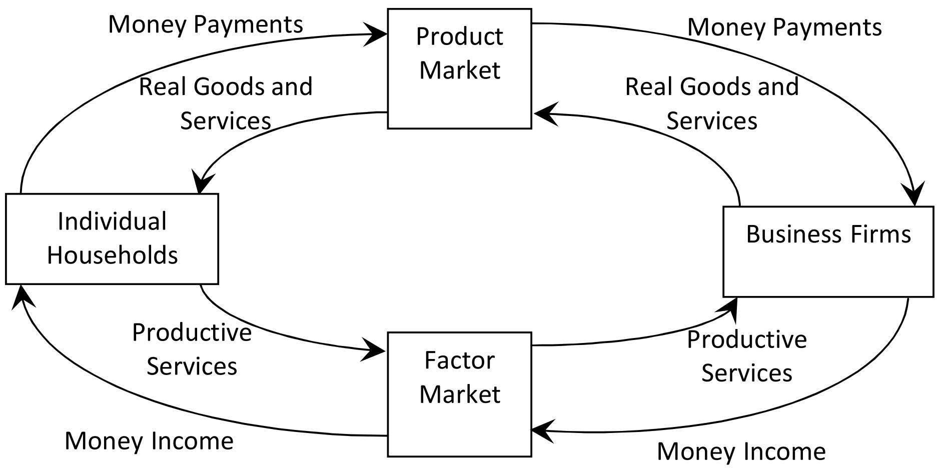

Figure 6-3: The Circular Flow of Economic System

Source: Nadar and Vijayan, 2009

In reality, economic processes require extracting resources from the environment, the consumption of these resources (transforming them into end-products for consumption or direct consumption), and disposal of transformed and dissipated resources (wastes) back into the environment (Boulding, 1966; Turner et al., 1994; Thampapillai, 2002). These two flows are illustrated in Figure 6-4: that is, utilization of resources and amenities (R and A) in the economic processes and the disposal of waste (W) back into the environment. As a result, the natural environment will no longer retain its equilibrium while the quality of the natural environment is degraded by both types of flows: sources and sinks (Turner et al., 1994; Thampapillai, 2002). The standard flow model of the economic system defines economic equilibrium in terms of monetary flow but does not consider a materials balance approach to acknowledge the two types of flows between economic processes and environment. Turner et al. (1994) and Thampapillai (2002) presented an expanded model of the economic system which acknowledges the role of the natural environment.

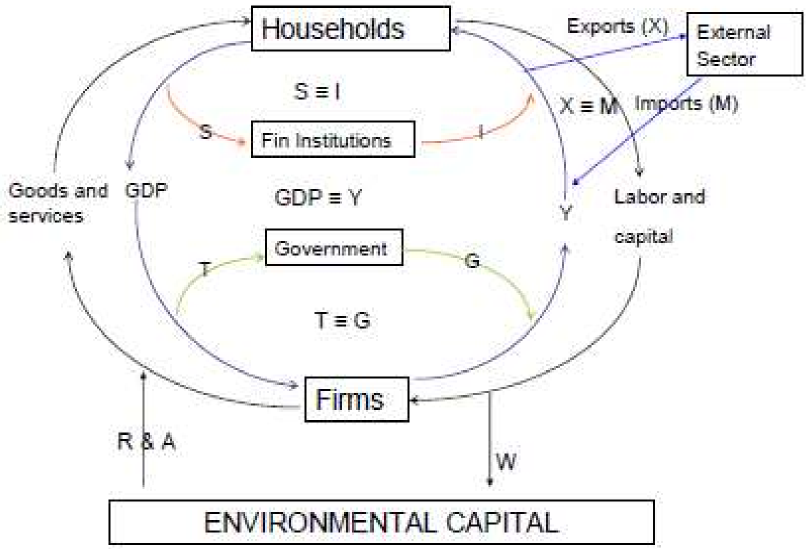

Figure 6-4: Economic System Revised for Materials Balance Principle

Source: Thampapillai, 2002

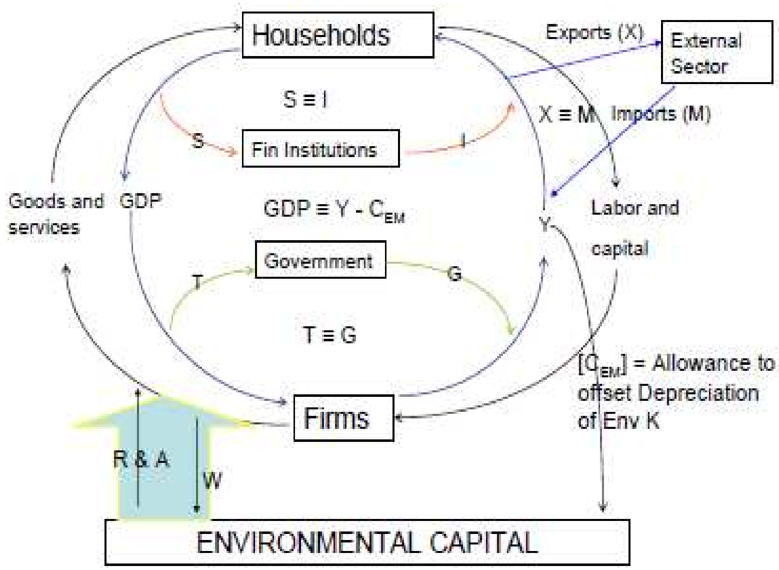

Figure 6-5: The Revised Model for Economic System – Materials Balance and Entropy

Source: Thampapillai, 2002

Going further, it is apparent that both flows denoted by "R and A" and "W" in Figure 6-4 impact the environment's ability to provide those services due to the increasing demand on these service flows (Hanley et al., 2001). Therefore, Thampapillai (2002) stated that to attain equilibrium in this expanded model, the economic system has to compensate what it harnesses from the natural environment by injecting a part of its output into it as shown in Figure 6-5.

6.4. Interactions between Natural Environment and Economic System

Section 6.2 explained the importance of the natural environment in the sustainable development paradigm while Section 6.3 reviewed the concepts of Environmental Economics which emphasised the role of the natural environment in the economic and development processes.

It is now understood that the economic and development processes operate inside the natural environment (Hanley et al., 2001) and that the economic system is underpinned by and cannot operate without the support of the natural environment though not vice versa (Turner et al., 1994). Hence, in order to achieve environmental sustainability in economic and development processes, the interactions between the economic process and the natural environment should be considered. Graham (2003, p. 22) also emphasized that construction process and constructed items depend on natural environment for all of their resources and the natural environment provides services for the survival of living system. Therefore, the practitioners in the construction industry need the knowledge of, relationships that either exist between constructed items and natural environment, or that are formed during the construction process. This understanding enables these practitioners to make decisions that form sustainable relationships.

In this view, this study necessitates identifying the requirements for achieving environmental sustainability in development processes. The study of these interactions will guide researchers to understand these requirements. This section reviews the literature on these interactions and summarizes them. The interactions will then be discussed in detail in order to determine the requirements for achieving environmental sustainability in economic and development activities. They would subsequently be considered in the conceptual framework of the study.

de Groot (1992) developed a system to better explain the functional interactions between human society and the natural environment as shown in Figure 6-6. The system proposed has both positive and negative aspects and has been divided into four types of interactions, namely, environmental goods and services, environmental hazards and risks, environmental impacts, and environmental management. While the two former interactions show the impacts of the natural environment on human needs and activities, the latter two show the impacts on the natural environment of human needs and activities.

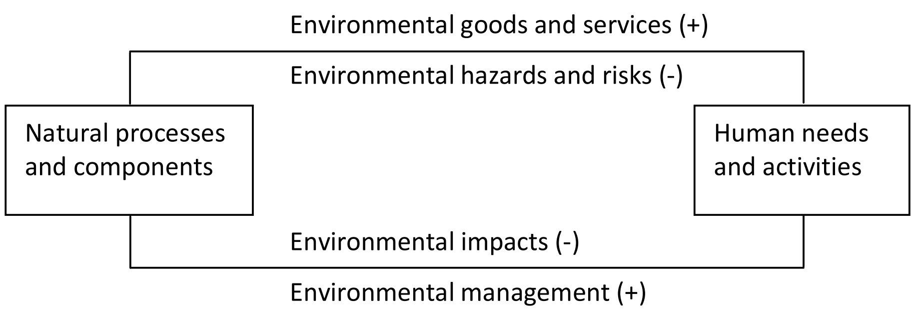

Figure 6-6: Functional Interactions between Human Society and the Natural Environment

Source: de Groot (1992)

Daly's (1994) notion of moving from an empty world to a full world explains how the economy is operating within the ecosystem and obtains matter and energy in the forms of production factors from that system while releasing them back into the ecosystem in the form of wastes, and which makes natural capital scarce (see Figure 6-7). Figure 6-7(a) illustrates the time when the economic subsystem was small relative to the global ecosystem. Figure 6-7(b) shows a situation much nearer to today in which the economic subsystem is very large relative to the global ecosystem. Hence, Daly (1994) emphasised the need for investment in natural capital and demanded a deceleration in the depletion of non-renewable natural capital.

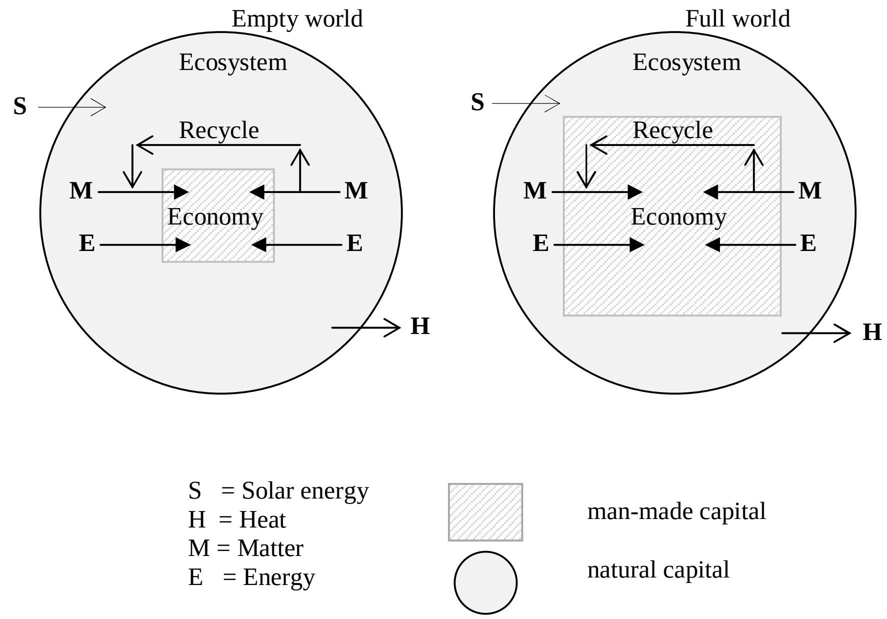

Figure 6-7: Revising the Pattern of Scarcity from Man-made Capital into Natural Capital

Source: Daly (1994)

Turner et al. (1994) drew attention to the multifunctional nature of environmental resources which offer a wide range of economically valuable functions and services. These include provisions of natural resources (both renewable and non-renewable resources), sets of natural goods (landscape and amenity resources), the waste assimilation capacity, and the life-support system.

van den Bergh (1996) showed how interactions between the environment and economy result in the extraction of inputs from the environment in the form of both renewable and non-renewable resources, and the emission of economic output of waste into the environment. Both of these interactions degrade environmental quality.

Under the ‘natural capitalism’ phenomenon introduced by Lovins et al. (1999), not only is the value of ecosystem services as the largest component of capital underscored but four major shifts have been proposed with regard to economic activities to preserve or enhance this natural capital, namely, enhancing the productivity of natural resources, redesigning production according to biological models, fundamental changes to business models, and reinvestment in natural capital. With these shifts, they expect to reduce wasteful and destructive flows of resources from depletion to pollution by reducing resource usage and, thereby, extraction and waste generation while at the same time restoring, sustaining and expanding natural capital to offset environmental impacts caused by economic activities. Among examples of such shifts provided by them are: lean manufacturing; closed-loop production systems like making compost; purchasing floor-covering service contracts rather than floor carpets; and merging plantation projects with power projects to offset carbon emissions of power plants and so on.

Hanley et al. (2001) explained four service flows which are provided by the natural environment to the economic system, namely, provision of inputs of raw material and energy sources, provision of waste sink, provision of direct source of amenity, and the provision of basic life-support services. In addition, they identified two impact flows from the economy to the environment, namely, waste disposal and impacts on biodiversity.

As noted earlier in the works by Thampapillai (2002), the natural environment provides three main functions to the economic system in a supporting role. These are provision of raw materials, receptacle for wastes, and provision of amenities. Furthermore, Thampapillai (2002) suggested that a share of the final output of the economic system should be redirected to the environment for two types of activities in order to achieve equilibrium between the environment and the economic system. These are: restoration of lost (non-functional) endowments and maintenance of existing (functional) endowments which will maintain and, in some instances, even expand the flow of services from the environment.

Common and Stagl (2005) and Asafu-Adjaye (2005) identified four interactions between human economic activities and the natural environment, namely, resource extraction from the environment for production and consumption, waste disposal to the environment as a result of both production and consumption, provision of amenity services by the environment, and life-support services by the environment.

Pearce and Turner (1990) explained two major flows between the environment and the economic system, namely, flow of environmental inputs to economy which are in-situ resources of the environment such as materials, energy and land, and the flow of waste output from the economy to the environment.

Table 6-1 presents a summary of the interactions between the economic system and the natural environment found in the literature reviewed in this research. Since this study aims to propose changes to the current patterns of economic activities in order to achieve sustainability, the interactions are listed from the perspective of activities of the economic system.

Table 6-1: Interactions between Economic System and Natural Environment

Interactions	**Sources**
Using environment as a source of land	Pearce and Turner (1990); de Groot (1992); Turner et al. (1994)
Using environment as a source of materials and energy sources	Pearce and Turner (1990); de Groot (1992); Daly (1994); Turner et al. (1994); van den Bergh (1996); Lovins et al. (1999); Hanley et al. (2001); Thampapillai (2002); Common and Stagl (2005); Asafu-Adjaye (2005)
Using environment as a sink for disposing of waste	
Investing in natural capital to maintain natural capital stock	de Groot (1992); Thampapillai (2002)
Investing in natural capital to enhance natural capital stock	de Groot (1992); Daly (1994); Lovins et al. (1999); Thampapillai (2002)
Impacting biodiversity	Hanley et al. (2001)
Using environment as a flow of amenities	de Groot (1992); Turner et al. (1994); Hanley et al. (2001) Common and Stagl (2005); Asafu-Adjaye (2005)
Using environment as a flow of life support services	

Each interaction is defined hereafter and major interactions are determined which provide the basis of the conceptual framework for environmental assessment in infrastructure projects.

6.4.1 Using Environment as a Source of Land

A holistic approach to defining "Land" can be found in the Land and Water Bulletin of the Food and Agriculture Organization of the United Nations (FAO) in 1997 as follows:

> "*Land is a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, and so on).*"- *FAO (1997, p.11)*

FAO (1997) also explained the various functions of land which are presented in Table 6-2. Throughout the history of economics, the importance of productive land to the economy and the adverse impacts of its depletion due to increasing economic activities have been recognized. For instance, Ricardo (1817) presented his growth model by considering the economy as a large farm and highlighted the reduction of productive land with population growth (Thampapillai, 2002; van den Bergh, 1996).

Table 6-2: Functions of "Land" as presented by FAO (1997)

Function	**Description**
Production Function	Land provides the basis for many life-support systems through production of biomass that provides food, fibre, fuel, timber and other biotic materials for human use, either directly or through animal husbandry, including aquaculture, inland and coastal fishery.
Biotic Environmental Function	Land lays the basis of terrestrial biodiversity by providing the biological habitats, and the gene reserves for plants, animals and microorganisms both above and below ground.
Climate-regulative	Land and its use are a source and sink of greenhouse gases and form a co-determinant of the global energy balance -

Function	reflection, absorption and transformation of radiative energy of the sun, and of the global hydrological cycle.
Hydrologic Function	Land regulates the storage and flow of surface and groundwater resources while influencing their quality.
Storage Function	Land is a storehouse of raw materials and minerals for human use.
Waste and Pollution Control Function	Land has a receptive, filtering, buffering and transforming function of hazardous compounds.
Living Space Function	Land provides the physical basis for human settlements, industrial plants, social activities and recreation.
Archive or Heritage Function	Land is a medium to store and protect the cultural evidences of the history of mankind, and a source of information on past climatic conditions and land uses.
Connective Space Function	Land provides space for transportation, and movement of plants and animals between discrete areas of natural ecosystems.

Although land could be considered as a unique resource that is perfectly inelastic in supply and available to society as a fixed total quantity (Hanley et al., 2001), a greater concern with changes in land quality can be seen with the rapid growth in economic activity (FAO, 1997). Hence, land quality assessment and land evaluation have become important programmes in the FAO since its establishment in 1945 (FAO, 1997). Another historical development is the Global Assessment of Soil Degradation (GLASOD) launched by United Nations Environment Programme (UNEP) in 1987, in cooperation with the International Society of Soil Science (ISSS) and FAO. Furthermore, UNCED's Agenda 21 devoted five chapters to land-related matters under Land Use (Chapter 10), Deforestation (Chapter 11), Desertification and Drought (Chapter 12), Sustainable Mountain Development (Chapter 13), and Sustainable Agriculture and Rural Development (Chapter 14).

The opportunity costs of land use are usually compared in terms of the value of the potential agricultural output of the particular land in question. This is because the major use of land is agriculture for food production which is one of the basic necessities of society. Many studies have been conducted to date on land quality and land degradation and their impacts on agriculture and vice-versa in relation to policy studies, productivity and economic intervention. Walpole et al. (1996) stated that the production function includes the notion of land quantity as an input to production. However their theory does not reflect the notion of land quality because their attempt was to analyse the effects of land quantity on agricultural output. Singh (1995), however, observed considerable threats to economic outputs in one of the north-western Indian states, in terms of reductions in agricultural production, farm income and farm labour employment, due to land degradation.

Since infrastructure items utilize large land areas, the type of land, land quality and land quantity have significant impacts on the environment as well as on future economic activities depending on the type of infrastructure. For instance, large-scale hydropower projects utilize large areas of land (the reservoir under the Victoria Dam, for instance, which supports the largest power station in Sri Lanka, covers a 2270ha of surface area) which may have destroyed forests, cultivable lands and natural water sources due to damming and clearing of banks and, consequently, may have involved the loss of many natural and man-made capital. Lunugamwehera project experienced bad siting due to the clearing of more land than was necessary given the capacity of the reservoir (Withanage, 1998), and a large amount of fertile land was lost due to the Mahaweli and Upper Kothmale hydropower projects (Withanage, 1998).

Even coal-fired thermal plant projects utilize considerable areas of land to avoid the adverse effects of emissions. In the power sector in Sri Lanka, the Norochcholai coal-power plant project site covers a total of 95 hectares (Media Centre for National Development of Sri Lanka, 2011).

Therefore, the way land is used can affect the future availability of productive land and other natural features inherent in those areas in terms of both quantity and quality. Therefore, one of the major requirements in environmental sustainability is the proper management of land use to minimize these effects. In this regard, one solution would be to minimise the need for acquiring new productive lands for economic activities in terms of the quantity of land acquired and another would be to consider the quality of land that is intended to be used. This would mean taking into consideration the composition of the land, that is, whether it is greenery, wetland, marshy land and so on and the effects of the project on the land quality. Such practices would factor in the productivity of the land and the opportunity cost of one land use over another. Thus, two aspects are considered in this study under ‘usage of land’ in the conceptual framework provided in Figure 6-8.

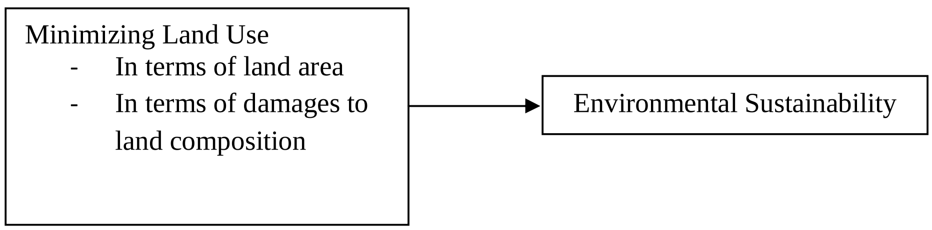

Figure 6-8: Minimizing Land Use Issues as a requirement of Environmental Sustainability

6.4.2 Using Environment as a Source of Materials and Energy Sources

The environment provides inputs to the economic system, both raw materials and energy resources **(**Hanley et al., 2001), for production and direct consumption (Common and Stagl, 2005; Asafu-Adjaye, 2005). Harnessing of materials and energy sources may reduce the amount of available materials and energy sources (Hanley et al., 2001).

In terms of their potential for natural growth, resources can be categorized as ‘non-renewable’, ‘exhaustible’ or ‘renewable’ (Turner et al., 1994; Hanley et al., 2001). Although the term ‘exhaustible’ can also be used for resources with a fixed overall quantity which lessen over time with usage, because many renewable resources can also become exhaustible due to overharvesting (Hanley et al., 2001), the classification of renewable and non-renewable would better explain the distinction (Turner et al., 1994) than renewable and exhaustible. Renewable resources can grow and regenerate naturally under suitable conditions while non-renewable resources do not have this capability (Turner et al., 1994; Hanley et al., 2001, p.317). Hence, the more people utilize non-renewable resources today, the less of the resource there would be for future use, thus threatening environmental sustainability. There is thus a trade-off between use of the resource now and its use in the future (Common and Stagl, 2005, p.114). For non-renewable resources, therefore, the challenge is to determine the ‘rate of depletion’ of the resource and the total amount that should be extracted. The ‘sustainable yield concept’, on the other hand, is applicable in the case of renewable resources (Turner et al., 1994, p.221; Common and Stagl, 2005, p.115). This concept is applicable where it is possible to exploit a renewable resource by extracting a quantity that is equal to its natural growth while maintaining a constant total stock (Common and Stagl, 2005, p.115). However, both types are under threat of overuse and extinction.

Similarly, different primary energy sources are utilized from both renewable and non- renewable sources such as petroleum, natural gas, coal, hydro, nuclear, biomass, geothermal, solar and wind (Hanley et al., 2001, p.328). Energy plays many roles in the modern economy, namely, as a consumer good in daily life, as a factor of production combined with labour and capital, and as a strategic resource which provides value for nations (Hanley et al., 2001, p.328). The world’s production and consumption of energy is ever increasing while most sources in use are non-renewable, a major reason being the low prices (Hanley et al., 2001, p.329). This is mainly due to the fact that energy prices do not reflect the value of the natural resources but only the cost of extraction so that neither the costs of extraction nor profits clearly reflect actual resource depletion and the resultant growing scarcity.

The earth is considered as a closed system in terms of materials and receives only a limited amount of outside energy (solar energy) within a certain time period. Therefore, materials and energy considered as scarce resources and with increased economic activity they become more scarce. However, different strategies would reduce the demand for new materials and energy.

The harnessing in addition may cause damage to the environment depending on the type of source and method of extraction. Attention should be paid thus not only to the reduction of the amount of resource usage but to the selection of the material sources with the minimum environmental impacts. For example, quarries that are developed within national parks cause more damage to biodiversity and amenity flow than those in brownfield areas (Hanley et al., 2001). Similarly, logging in a rainforest impacts biodiversity more than logging in a planted forest. Although the quantity of materials extracted might remain the same in the two cases, the damage caused to the surrounding environment would be different.

It is therefore clear that the patterns of use of materials and energy in economic activities greatly affect the future availability of those resources while extraction harms the natural environment. Thus, proper management that can minimize usage and determine the right source is considered a major requirement in environmental sustainability. Since natural growth in renewable and non-renewable resources is different, thus imposing different limits on their usage, the use of non-renewable resources and other materials is considered separately in the framework in this study as shown in Figure 6-9.

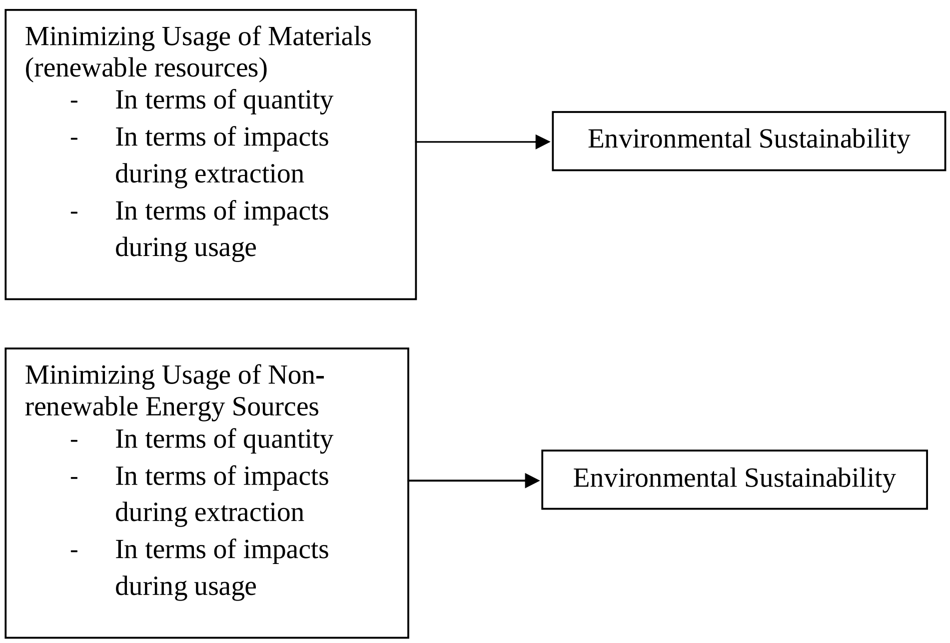

Figure 6-9: Minimizing Usage of Materials (Renewable) and Non-renewable Energy Sources as requirements of Environmental Sustainability

6.4.3 Using Environment as a Sink for Disposing of Waste

As discussed earlier, economic systems transform materials and energy during production and consumption. The production process, while producing useful products, generates residuals. When these residuals are not inserted again into the economic system via reusing or recycling, they become waste (Common and Stagl, 2005, p.349). Similarly, useful products also become waste at the end of their lives. Moreover, waste cannot be destroyed in an absolute sense as explained under the first law of thermodynamics; nor is 100% recycling possible if one considers the second law of thermodynamics. Therefore, they will eventually be discharged into the environment (Turner et al., 1994, p.41). The natural environment has an assimilative ability to handle these wastes up to a certain extent which is known as the “assimilative capacity” (Thampapillai, 2002). Various parts of the natural environment act as waste receptacles: for instance, natural water sources receive liquid and solid waste; land usually receives solid waste; the atmosphere absorbs gas wastes; and trees absorb carbon dioxide. However, when the waste disposal is continuous and intense, it may exceed the assimilative ability of the environment, thus preventing the natural environment from fulfilling its function as a waste sink (Thampapillai, 2002) and affecting its other functional performance as well. When the chemical or physical change that occurs in the environment is harmful to living organisms, it is known as pollution (Common and Stagl, 2005, p.98). Thus, not all waste emissions are considered as pollution. Consequently, this imposes limits on the economic system while threatening sustainability (Turner et al., 1994, p.41; Common and Stagl, 2005, p.114). It is however not just the quantity of waste but also the quality of waste that will harm the environment. Paul (2012) highlighted the importance of disposing waste into a proper location and also the type of waste disposing of. The harm caused by even a small amount of hazardous waste and/or untreated waste may be more severe than that caused by the same quantity of treated waste. Similarly, disposing waste into a river can be more severe than that caused by the same quantity of waste disposed of into a landfill site.

Since infrastructure involves large-scale construction works and operates over long time periods, they generate large amounts of waste in various forms throughout the project life cycle from construction to disassembly depending on the type of project. For instance, large-scale power projects generate large amounts of solid waste during construction whereas coal-fired thermal power plants generate large amounts of gas emissions during their operation. Among the waste problems associated with coal power plants are: discharge of ash containing radio-active minerals, including uranium, thorium, and other heavy metals, which present health hazards; the release of major conventional air pollutants during the coal combustion process (for example, particulate matter such as NO_x, SO_2, Hg, and other toxic substances such as CO_2 and CH_4); and solid waste pollution problems due to plants operating without an effective fly ash capture (Mamurekli, 2010).

The use of the natural environment as a sink also affects the ability of the environmental system to function well. Hence, another way to achieve environmental sustainability is to control the use of the natural environment as a waste sink through reducing waste disposal and damages. These aspects are considered as major requirements to achieve environmental sustainability as Figure 6-10 shows.

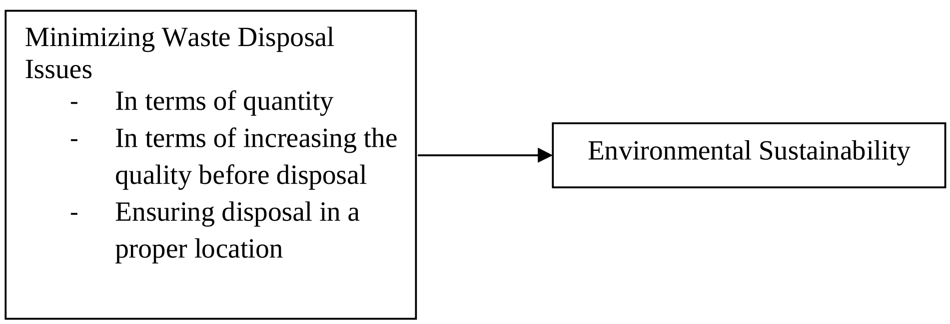

Figure 6-10: Minimizing Issues under Waste Disposal as a requirement of Environmental Sustainability

6.4.4 Investing in Natural Capital for Maintenance and Enhancement of Natural Capital Stock

The introduction of the role of the natural environment into the standard economic system model included the materials balance principle explained under the first law of thermodynamics. The model should also be extended to capture the entropy law as well. As discussed in earlier sections, zero harm to environment is not possible with economic activity. Therefore, a way to compensate the environment should be factored into the economic system. According to Thampapillai (2002), if environmental endowments are the ultimate factors of production, then the final output (that is, the sum total of all income from goods and services) explained under the standard economic system model should not be exclusively used up in consumption; nor should investment be undertaken only within the economic system as assumed by economists in general. Thampapillai (2002) therefore stated that a part of this final output must be reinvested in the environment. Similar to the equilibrium of input and output flows between households and firms explained in the standard economic system model, this expansion denotes the equilibrium between the economic system and the environmental system driven by the laws of thermodynamics (Thampapillai, 2002).

According to Principle 3 of the United Nations Conference on the Human Environment (held in Stockholm) in 1972, “the capacity of the earth to produce vital renewable resources must be maintained and, whenever practicable, restored or improved”. As explained by Thampapillai (2002), this investment can be done in two forms. One form comprises the activities that are designed to maintain the flow of services from endowments that currently provide services (functional), which is similar to offsetting the wear and tear of capital goods. Among the practices that demonstrate this form are: periodic treatment of a river which is getting polluted but still provides services so that the river system is helped to continue its services or the treatment of waste before discharging it into the natural environment. These kinds of investment in natural capital are important to ensure a continuous flow of goods and services from natural environment.

Thampapillai (2002) explained another form of investment as activities that are designed to restore the flow of services from endowments which have ceased to provide services (non-functional). This includes restoring previously damaged or lost endowments such as rivers that have been rendered unusable due to algal blooms; detoxifying unusable soils for urban or rural development; reforestation of areas that had been cleared for long-term open cut mining. Such actions can expand the set of resource endowments (Thampapillai, 2002).

Daly (1994) also emphasized the need for investment in natural capital. He discussed of investing in new natural capital to cope with the needs of growing economic activities which cannot be met with only manmade capital or where natural capital cannot be substituted with manmade capital. Therefore, investing in natural capital to maintain and enhance natural capital stock is considered another requirement for environmental sustainability. Thus, two aspects are considered under in the conceptual framework provided in Figure 6-11.

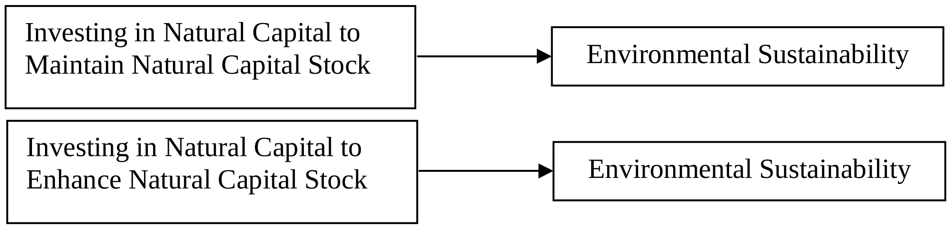

Figure 6-11: Investment in Natural Capital to Maintain and Enhance Its Stocks as a Requirement of Environmental Sustainability

6.4.5 Impacts to Biodiversity

According to Jansson et al. (1994) 'Biodiversity' is a well-known term that has not been clearly defined so that, more often than not, it refers to species diversity. While Parker and Cranford (2010) defined that richness of life on earth is 'Biodiversity' in its broadest sense, United Nations (1992) gave a more specific definition in the Convention on Biological Diversity (CBD) as follows:

> *'The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (United Nations, 1992, p.3).*

Turner et al. (1994) also stated that biological diversity or 'biodiversity' is a term for the extent of variety in nature in terms of species of plants, species of animals, species of microorganisms and the ecosystems and ecological processes of which they are a part. Diversity refers to variety rather than numbers of individuals within a species. Biodiversity occurs, and tends to be analysed, at all levels such as genetic, species, and ecosystems (Parker and Cranford, 2010; Turner et al., 1994). Interactions between the many species in an ecosystem, and between them and the environment's physical and chemical components, are also very important and these highly intricate relationships make an ecosystem more valuable than the mere sum of the species it contains (Narasaiah, 2005). Plants, animals and microorganisms have genes with stored information called genetic information or genetic diversity. The number of different species gives the measure of species diversity and the variety of habitats, biotic communities and ecological processes is known as ecosystem diversity (Turner et al., 1994).

According to Hanley et al. (2001), biodiversity loss involves more than the loss of a particular species, making it a cause of concern for three reasons. Firstly, direct impacts such as loss of genetic material for food crops or as a source of medicine; secondly, the critical role played by a species in maintaining ecosystem and providing a range of ecosystem services; and, finally, the loss of non-use benefits such as aesthetic. Moreover, biologically diversified ecosystems seem more productive (Narasaiah, 2005) and provide a greater flow of ecosystem services than non-diverse systems (Hooper et al., 2005; Flombaum and Sala, 2008). More importantly, diversity provides an important property of natural systems which is known as ‘resilience’ due to their ability to withstand shocks such as drought and fire (Hanley et al., 2001), which also helps ecosystems to resist alien species and diseases and to recover faster in the event of disruption (Narasaiah, 2005). It should be noted that natural capital cannot be conserved if conservation activities are confined to protected areas (IUCN, 2010). Instead, they should be incorporated into every economic activity that has impacts. Principle 4 of the United Nations Conference on the Human Environment (Stockholm) in 1972 stated that safeguarding wildlife and its habitat is a responsibility of mankind and, therefore, conservation of these natural resources must receive importance in planning for economic development as well.

Since infrastructure utilizes large areas of land including forests and water features, they may have a grave negative impact on the biodiversity of those areas. For instance, large scale hydropower projects have a significant impact on the diversity of aquatic species and systems.

Although natural resources are conserved in terms of the quantity of total natural capital stock through minimizing resource usage and by investing in natural capital, the diversity of that natural capital stock is of immense importance in continuing with the functionality of the life-supporting ecosystems (Jansson et al., 1994, p.84).

As Newton (2007) pointed out, some of the losses of genetic diversity in threatened species are irrecoverable. The “Rio+20” conference also recognized the severity of global biodiversity loss and the degradation of ecosystems (UNCSD, 2012). It also endorsed the intrinsic value of biological diversity and its critical role in maintaining ecosystems that provide essential services, which are critical foundations for sustainable development and human well-being (UNCSD, 2012). Hence, conserving biodiversity and reducing the negative impacts on biodiversity are regarded as the major requirements for environmental sustainability as shown in Figure 6-12.

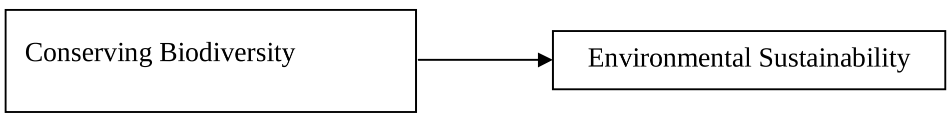

Figure 6-12: Conserving Biodiversity as a requirement for Environmental Sustainability

6.4.6 Use of Environment as a Flow of Amenities

People can derive utility in terms of happiness satisfaction, pleasure and stimulation from amenity services provided by the natural environment (Common and Stagl, 2005; Hanley et al., 2001). These include a great number of different sources such as scenic beauty, wildlife, treks, and unspoilt beaches which facilitate activities like sightseeing, bird-watching, hiking, fishing, sunbathing, swimming and wilderness recreation (Thampapillai, 2002; Hanley et al., 2001; Common and Stagl, 2005).

It is noted that these environmental features that support amenity services can be effectively similar to natural resources and that therefore impacts on these resources will directly impact on the ability of the environment to provide amenity services. Natural features are lost due to improper land selection, depletion of some resources due to overharvesting, pollution due to waste accumulation (Common and Stagl, 2005, p.115; Hanley et al., 2001, p.5), and disturbances to the functioning of the ecological systems due to loss of biodiversity. For instance, loss of forests, waterfalls and other water features due to large-scale hydropower projects is a consequence of land acquisition which also leads to loss of many amenity services such as scenic beauty, wilderness recreation and water-related activities.

Since land use, resource use, waste sink and impacts on biodiversity are the causes that disrupt the amenity services which are discussed in Sections 6.4.1 to 6.4.2, 6.4.3 and 6.4.5, the use of the environment as a flow of amenities is not included separately in the conceptual framework in this study.

6.4.7 Use of Environment as a Flow of Life-Support Services

The environment provides the economic system with the biophysical necessities of life, namely, food and other energies, mineral nutrients, air and water (Jansson et al., 1994, p.6), through basic life-support services including climate regulation, operation of the water cycle, regulation of atmospheric composition, and nutrient cycling (Hanley et al., 2001, p.5). Maintaining the life-support services of the environment is important not only for the survival of the economic system but even for human survival. Jansson et al. (1994, p.89) stated that the only way to realise ecological sustainability is to keep the natural life-support systems working.

Similar to that of provision of amenity services, ecosystems supplying life-support services are affected by the factors discussed under sections 6.4.1 to 6.4.2, 6.4.3 and 6.4.5. Hence, it is not included separately in the conceptual framework in this study.

6.5. Other Factors to be Considered in the Conceptual Framework

The factors identified in the previous sections contribute directly to minimising the impacts on the natural environment and to enhancing its status. As discussed in Section 3.7.3, several researchers have shown that the scope of ERSs should be broadened to embrace the wider agenda of sustainability. However, the review of the literature on sustainable development in Section 6.2 made it clear that, first, the natural environment should be sustained for everything else to be sustained. However, in developing countries, it is hindered due to the priority given to economic and social issues. Therefore, rather than just inserting economic and social factors into ERSs, this study reviewed the socio-economic barriers to environmental sustainability in the developing countries. Two major factors, namely, poverty and corruption can be identified as barriers to environmental sustainability in developing countries. Since project-level contributions to minimising the impacts of these barriers on environmental sustainability can be addressed in ERSs, they are considered in the conceptual framework.

6.5.1. Eradicating Poverty

The report of the Rio+20 United Nations Conference on Sustainable Development titled "The Future We Want", held from 20-22nd June 2012 at Rio de Janeiro, Brazil, highlighted the eradication of poverty as the greatest global challenge facing the world today and as an indispensable requirement to attain sustainable development (UNCSD, 2012). However, this is not a new issue in the discussions of sustainable development. Eradicating extreme poverty and hunger is Goal 1 of MDGs. Goodland and Daly (1993) also underscored reduction in poverty as a must for environmental sustainability. A study by Akinola et al. (2012) discussed the implications of poverty in the Nigerian context and showed that eradication of poverty is important to ensure environmental sustainability in Nigeria where the poor degrade the environment and its resources for survival.

A study on the poverty–environment relationship among rural households in Zimbabwe by Cavendish (2000) provided empirical regularities regarding the heavy dependence of poorer households on environmental resources for significant income generation. However, the study showed that richer households demand and use greater quantities of environmental resources in total than the poor. It moreover showed that though poorer households harness most of the natural resources, the end users are mostly richer households. Since poorer households harness natural resources to increase their income levels, poverty increases resource harnessing. At the same time, richer households demand more goods and natural resources. Hence, declining poverty may also significantly, though indirectly, increase resource harnessing.

However, if there is no inequality in society in terms of income levels, and if there are no divisions along the lines of rich and poor because all have a good quality of life, then the overall propensity to harness natural resources may decline because there is no induced poor to harness and sell natural resources since it is basic necessities that drive the demand for natural resources. Cavendish (2000) suggested that the maintenance of commons will be of great importance to the welfare of poorer households because they depend heavily on communally-held natural resources. It will also enable the survival of the natural capital stock because it would be shielded from degradation due to consumption.

Reardon and Vosti (1995) argued that poverty is usually measured in terms of income, consumption, or nutrition criteria. They called it “welfare-poverty”, which they thought was inadequate for the consideration of poverty measurements. Instead, they introduced the concept of “investment poverty”, measured in terms of the ability of people to make investments in resource improvements to maintain or enhance the quantity and quality of the resource base, and to forestall or reverse resource degradation. In this context, they showed that a person who is not “welfare-poor” can still be “investment-poor”.

Though poverty is one reason for environmental degradation in some countries, not all environmental degradation is linked to poverty. According to Reardon and Vosti (1995), this is especially the case in developing countries where poverty is an overwhelming issue in the discussion on sustainable development. They provide examples of pollution due to large-scale agriculture by rich farmers or overexploitation of forests by large and capital-intensive lumber merchants which can ravage the environment without any contribution from the poor to such destruction. This situation can be seen in Sri Lanka too where large areas of forests with large trees are disappearing due to the activities of capital-intensive lumber merchants in the wet zone, an issue even more serious in its impact than environmental degradation in the dry zone due to “chena” cultivation or the small-scale forest or wood fires started by poor farmers. “chena” cultivation is alternatively called as shifting agriculture which involves the use of “slash and burn” methods to clear the land (Sandika and Withana, 2010).

As also reflected in the findings by Cavendish (2000), alleviating poverty alone will not necessarily protect the environment because increase in wealth and purchasing power may again result in overuse of resources or increased pollution if that aspect is not separately addressed. Therefore, specific policy actions will be needed to optimize the achievements on the development front while balancing resource usage.

Goal 1 of the MDGs, namely, “Eradication of Extreme Poverty and Hunger” consists of three targets: halving, between 1990 and 2015, the proportion of people whose income is less than $1.25 a day; achieving full and productive employment and decent work for all, including women and young people; and, halving, between 1990 and 2015, the proportion of people who suffer from hunger (United Nations, 2013). Unemployment and low incomes worsen poverty and hunger while having an adverse impact on food security which would result in a workforce of low productivity in such countries. Moreover, in what might be termed a vicious cycle, low productivity would again affect the economic growth of the country and exacerbate the poverty issue.

Food security is not just the amount but also the quality of food, that is, nutrition levels in the food, people consume since human and economic development rely on a strong and healthy workforce while malnourished children could suffer permanent physical and cognitive damage as well as being less likely to attend school and to suffer from learning deficits. Malnourishment therefore would have long-term repercussions by affecting the future health, welfare, and economic well-being of young children in addition to increasing mortality rates (World Bank, 2012a), all of which would have an impact on the ability of developing countries to raise a productive workforce over time. Moreover, education is the key to development and quality in basic education, vocational training, and skill acquisition throughout life are indispensable tools to eradicating poverty (Singh, 1999).

Although a downward relationship between poverty and environmental degradation cannot be assured in all the cases, in many cases, environmental degradation receives less attention mostly due to the focus on the other socio-economic problems of developing countries discussed above. In fact, the tendency is to give priority to such socio-economic problems in political agendas even at the expense of the environmental impacts. Therefore, eradicating poverty will create the right background to address environmental issues in developing countries. However, effective environmental legislation and other measures should be implemented at the same time to ensure that environmental degradation will not be the outcome of rising income.

One may argue that poverty eradication cannot be addressed at project level. However, Ofori (2007) provided examples from Sri Lanka to show how privately owned businesses and firms can contribute to achieving MDGs. Although these may mostly take the form of donations and philanthropic programs, individual projects can contribute to eradicating poverty by providing direct and indirect employment opportunities to local people, both skilled and unskilled, and by avoiding any disturbance to natural capital stocks on which local people are heavily dependent to fulfil their basic needs such as food, shelter and medicine, and by providing education and training to the populace in the particular locale. The benefit of such involvement to the firm may be competitive advantage, tax exemptions, gaining of a marketing tool to promote the corporate image of the firm in question and so on.

According to the World Bank (2012a), individual projects can also invest in agriculture, create jobs, expand social safety nets, expand nutrition programs, enhance education, and promote gender equality in order to reduce poverty and hunger. However, such efforts at the project level have not received much attention in existing environmental assessment systems. However, since poverty is considered a barrier to environmental sustainability in developing countries, eradicating poverty is important for the purpose of achieving environmental sustainability. Thus such efforts at the project level can be appreciated through ERSs. Therefore, contributing to eradicate poverty is a requirement to achieve environmental sustainability in developing countries and, considered in the conceptual framework proposed in this study as shown in the Figure 6-13.

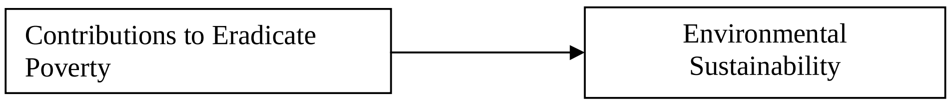

Figure 6-13: Eradicating Poverty as a Requirement for Environmental Sustainability in Developing Countries

6.5.2. Avoid Corruption

Robert and Walpole (2005) showed that corruption is known to hinder conservation efforts and even to contribute to environmental problems. Environmental degradation occurs when people place continuous demands on the environment to meet their needs and strain the natural resources, on the one hand, while conservation efforts seek to rein in people from overusing and abusing renewable resources by passing policies and changing behaviours on the other (Transparency International, 2008). In such situations, corruption enables individuals to supersede these frameworks and to endanger the environment (Transparency International, 2008). However, empirical research on this topic is limited (Robert and Walpole, 2005) and the extent of corruption's impact on environmental conservation efforts is still being debated (Smith et al., 2003). Investigations by several organizations have found that corrupt governing bodies in several countries, in sectors such as logging, fisheries and wildlife, have ignored environmental destruction. Among serious environmental degradation resulting from such corrupt behaviour are logging in Liberia, Brazil, Cambodia, India, Indonesia, and so on, overfishing in the Bering Sea, and ivory trafficking in Zambia (Transparency International, 2008).

The Rio+20 report stressed that the fight against corruption at both the national and international levels, is a priority because corruption is a serious barrier to effective resource mobilization and allocation by diverting resources away from activities that are vital for eradicating poverty and hunger as well as sustainable development. Corruption affects the environment and destroys a country's natural resources via inappropriate policy choices; limits information on existing environmental conditions, results in poor environmental management and so on (Transparency International, 2008).

Although high-level political corruption is difficult to address at the project level, individual project stakeholders can ensure that they are not involved in any such activities within the project, and that the project complies with the relevant laws and regulations. Environmental assessment systems can address such issues through their certifications by de-meriting projects or developers who are accused of engaging in corrupt activities. Avoiding corruption is considered important in achieving environmental sustainability in developing countries and hence, considered in the conceptual framework as shown in Figure 6-14.

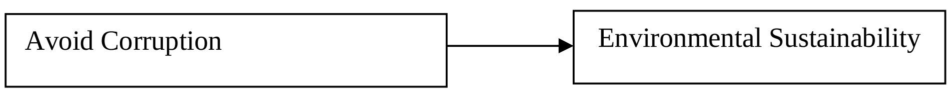

Figure 6-14: Avoiding Corruption as a Requirement for Environmental Sustainability

6.6. Conceptual Framework for Environmental Sustainability and Hypothesis

Eight major factors were identified as important for achieving environmental sustainability in the economic and development activities of developing countries which are denoted as ES1 to ES8 in Figure 6-15. Infrastructure projects constitute a major component of economic and development activities. Therefore, these factors should be considered when assessing environmental performance of infrastructure projects, and are used to form the conceptual framework for ERSs as shown in Figure 6-15.

Based on the literature review, the hypothesis addressed in this study is:

> Factors ES1 to ES8 are important in achieving environmental sustainability in Sri Lankan infrastructure projects.

In order to propose the conceptual framework for ERSs for assessing infrastructure projects in Sri Lanka, these factors are analysed for their severity/importance in Sri Lankan infrastructure development. ERSs assessing infrastructure projects should address these factors when assessing the performance of infrastructure projects towards sustainability.

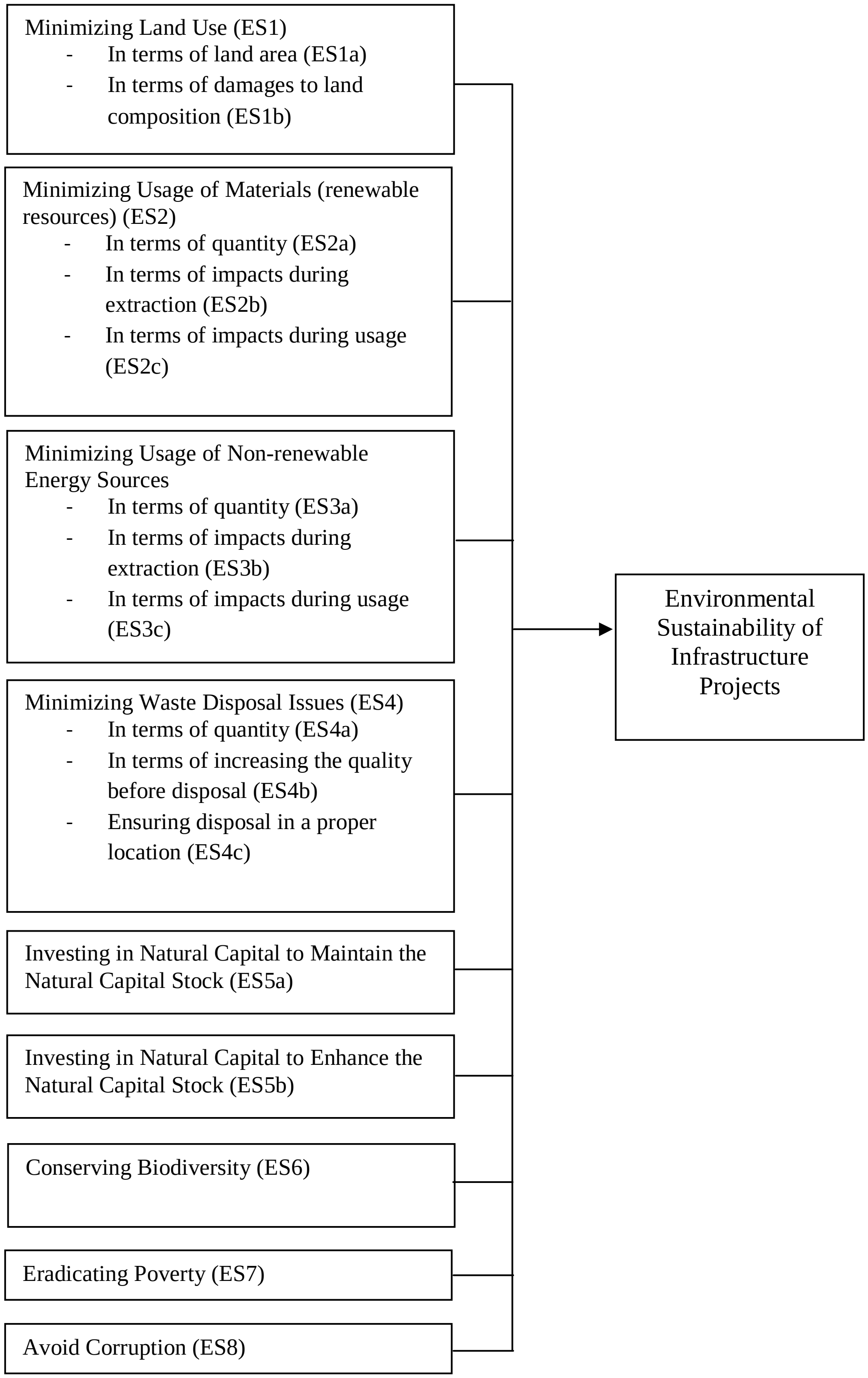

Figure 6-15: Requirements of Environmental Sustainability as Part of the Conceptual Framework

6.7. Summary

This chapter reviewed literature on the concept of sustainable development and the different views on sustainable development ranging from weak sustainability to strong sustainability. Given the actual physical limitations imposed by the natural environment on economic activities, the natural environment should be sustained for everything else to be sustained. There is also is an increasing emphasis on a green economy that recognizes the role of the natural environment. Embracing these aspects, the present study uses the view that sustainability of everything else depends on the natural environment. Some Environmental Economists have addressed the importance of the natural environment for economic activities based on the application of the laws of thermodynamics to the interactions between the economic system and ecosystem. These interactions can be addressed in ERSs for assessing the environmental performance of infrastructure projects since infrastructure constitutes a major element of economic and development activities in a country. However, since some socio-economic issues become barriers to environmental sustainability in developing countries, these issues should be minimised to increase attention to the environmental issues in the region. Project-level contributions to minimise such issues can be addressed in ERSs.

Interactions identified in the initial review were discussed in detail to determine the factors to be used in the conceptual framework. Likewise, the study identified eight main factors, denoted as ES1 to ES8, and the sub-factors under these as important for achieving environmental sustainability in infrastructure projects in developing countries after which the hypothesis was presented. In order to propose the conceptual framework for ERSs for assessing infrastructure projects in Sri Lanka, these factors are analysed in terms of their importance/severity with regard to Sri Lankan infrastructure development.

Chapter 7: Research Design and Methodology

7.1. Introduction

This chapter presents the research process, research design, the choice of sampling, the method of collecting data and the data analysis techniques used in the study. Before deciding on the research method, a research process was determined that would best address the research problem and achieve the research objectives. Suitable methods and techniques were selected accordingly. The chapter justifies these choices and also explains the approaches taken to maintain the validity of data and results.

7.2. Research Process

Considering the research problem and objectives, the study followed the process shown in Figure 7.1.

<u>Step 1</u>

The requirements for achieving environmental sustainability in infrastructure projects were determined based on the literature review on sustainable development, environmental sustainability and concepts of Environmental Economics. Chapter 6 reviewed these factors and denoted them as ES1 to ES8 with a few sub-factors under some ES factors. The hypothesis was presented based on these factors.

<u>Step 2</u>

These ES factors were analysed for their level of importance/severity in infrastructure development in Sri Lanka. Through this analysis, weightings were assigned to each factor and sub-factor. The conceptual framework for ERSs to assess the Sri Lankan infrastructure projects is proposed along with ES factors, their sub-factors and weightings. The framework reflects the need for regional adaptation of ERSs as explained in Chapter 3. The framework was then validated.

Step 3

SHP sector is the selected infrastructure project type in Sri Lanka to demonstrate the application of the conceptual framework to a specific infrastructure project type. Environmental problems and positive environmental impacts of SHP projects were identified under each factor in the conceptual framework.

Step 4

The study measured the relative importance of each factor identified in the SHP sector and demonstrated the application of the proposed conceptual framework for developing type-specific ERSs in the infrastructure sector in Sri Lanka.

7.3. Choice of Research Design

The research design is one of the most important components of research methodology since methodological decisions are informed and guided by the type of research design selected for a study (DeForge, 2010). Any scientific investigation, be it in the social or natural sciences, must begin with some structure or plan (Spector, 1981). It guides the investigator to address the research problem and to answer the research question (DeForge, 2010) by testing the hypothesis or interpreting the events (Tan, 2008). Such a structure is termed the research design (Spector, 1981).

The experimental design is suitable when the subjects (individuals or systems) and conditions (events or situations) can be manipulated and controlled by the researcher to ascertain their effects and test the relations (Tan, 2008; Spector, 1981). In the current study, the researcher is not able to control or manipulate subjects and conditions and, hence, the experimental design is not used in this study.

In a non-experimental research design, the researcher does not have complete control over the conditions of the study (McBurney and White, 2010). McBurney and White (2010) distinguished between several non-experimental research designs: observational, archival, survey and case studies. According to Yin (2003), case studies are appropriate when the research problem is a "how" and "why" type of question, the investigator has little control over events, and the focus is on a contemporary phenomenon within some real-life context. In observational research, the researcher simply measures behaviour in controlled settings. In archival research, the researcher examines already existing records.

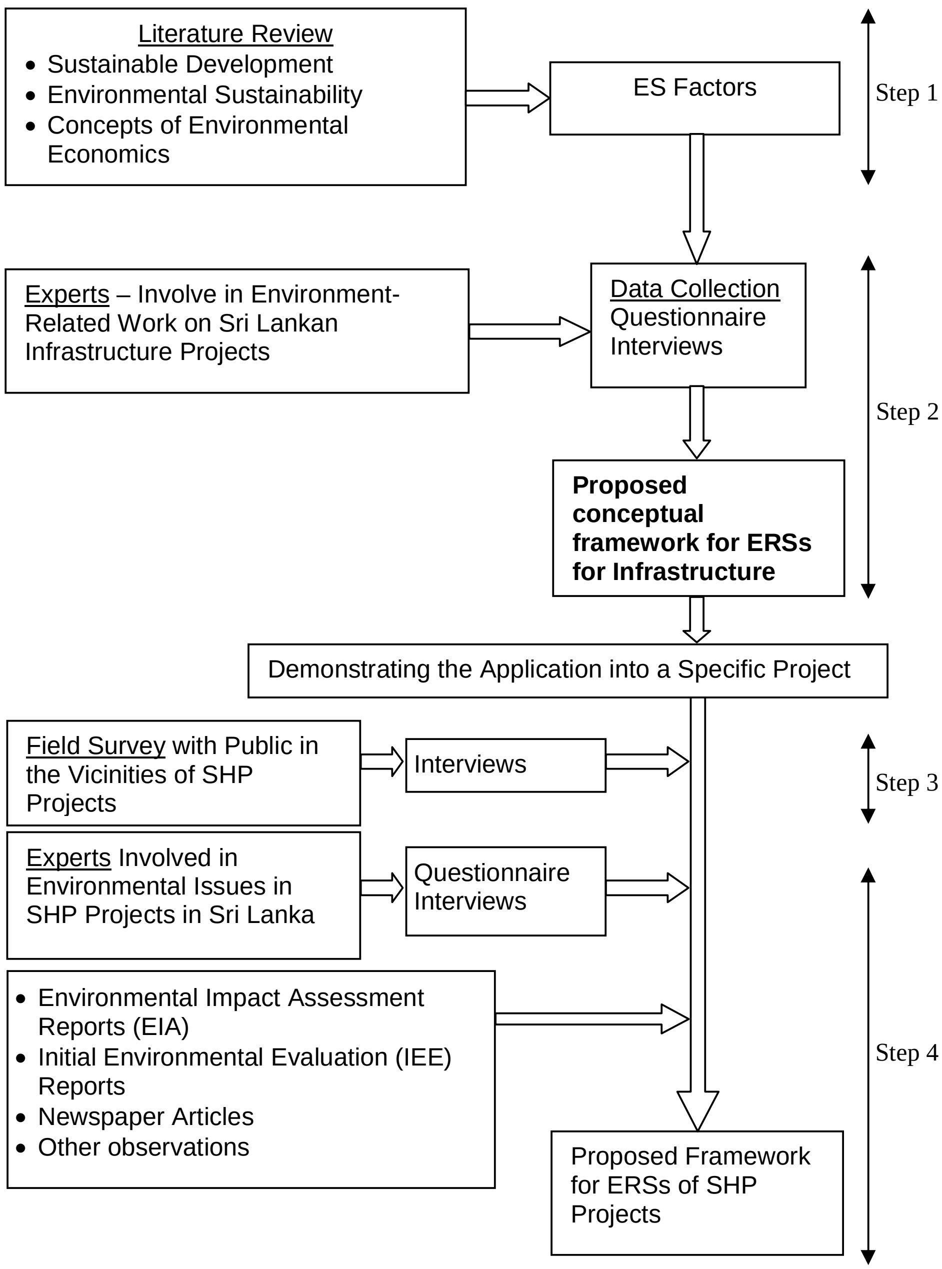

Figure 7-1: Research Process

A survey, on the other hand, is a systematic method of collecting data based on a sample (Tan, 2008). Surveys can be conducted with different purposes in mind and one such purpose can be to examine correlations among the responses and to look for possible patterns of cause and effect (McBurney and White, 2010). While a cross-sectional survey gathers information about a population at a particular point in time, a longitudinal survey collects data over time to monitor changes using different or same samples (Tan, 2008). Cross-sectional surveys are the most commonly used in social sciences and are the best suited to find the prevalence of a phenomenon, situation, problem, attitude, or issue (Kumar, 2005). Since the current study developed a framework based on relationships between environmental sustainability objectives and project issues and benchmarked the activities through expert opinion, a cross sectional survey is adopted for the framework development.

7.4. Choice of Sampling

Since the study focused on the environmental sustainability of infrastructure projects in Sri Lanka, the respondents had to be knowledgeable on environmental issues related to the infrastructure sector in Sri Lanka. Since the sample frame is difficult to specify, non-probability sampling was used (Tan, 2008). According to Tan (2008), non-probability sampling includes convenience, purposive, quota and snowball samples.

Convenience sampling, also known as accidental or availability sampling (Berg, 2007), selects elements which are easily accessible (Berg, 2007; Tan, 2008). These samples are unlikely to be representative and, hence, this sampling method is used to obtain preliminary information (Berg, 2007) for mainly exploratory work, or where a quick opinion is required (Tan, 2008). In the current study, convenience sampling is not used because in this type of sampling, respondents are not ensured to be knowledgeable regarding the area of study though they are expected to be**.**

Quota sampling fills the required stratum where the researcher determines the proportion and attributes of each stratum in arriving at the quota with non-probability methods (Berg, 2007; Tan, 2008). Since the current study did not use such stratum, quota sampling was not used.

Purposive or judgmental sampling chooses elements deliberately to be representative (Tan, 2008). When developing a purposive sample, researchers need to use their knowledge about the population to select a representative sample (Berg, 2007). Snowball sampling is regarded as similar to convenience sampling and is a chain referral sampling or respondent-driven sampling (Berg, 2007). According to Berg (2007), it is the best way sometimes to locate subjects with certain attributes or characteristics that are necessary for the study. When using the sample method, researchers begin with a few respondents and ask those respondents for referrals to others who possess the same attributes for the purpose of selecting additional respondents (Berg, 2007; Tan, 2008).

In the current study, a combination of purposive and snowball sampling was used where the researcher determined sample elements with certain attributes to be representative while more respondents were found through referrals.

7.5. Choice of Data Collection Method

Interviews, Questionnaires and Other Observations

Field visits, interviews and questionnaires were used as the methods of collecting data. The study administered a questionnaire to rank the importance of factors of the conceptual framework and also the specific factors in the SHP sector. In general, structured questionnaires were used though some questionnaires were filled during face-to-face interviews in order to ensure the reliability of the data collected. To obtain details of the real environmental issues of SHP projects in Sri Lanka, field visits were made and interviews were carried out with the general public as well as experts in the sector. In addition, documents such as EIA/IEE reports and newspaper articles were referred.

Interviews were first used to identify the impacts of SHP projects while another set of interviews with experts was then carried out to validate those impacts and to determine the solutions. Interviews were also carried out with experts in the infrastructure sector to find out information on current environmental issues in Sri Lankan infrastructure projects to supplement the survey results.

7.6. Sample Groups

For step 2, the study required responses from experts who are knowledgeable about the environmental issues related to the infrastructure sector. Therefore, this sample group for the survey consisted of experts in environmental studies and the infrastructure sector in Sri Lanka such as EIA experts, environmentalists, environmental economists, environmental managers, and academics in the field and members of environment-related non-government organizations.

The study employed a combination of purposive and snowball sampling, as mentioned previously. Firstly, the respondents were selected purposively on the basis that they were knowledgeable and experienced in environmental issues in infrastructure projects. This was done by browsing the contact details of officers in environment-related divisions in construction and development-related government and private institutions. It also helped to have an initial sample with both government and private-sector respondents. Then more respondents were found through referrals from these respondents.

A questionnaire for pair-wise comparison of ES factors (Appendix-1) was distributed among a total of 53 respondents. Face-to-face interviews were conducted with 18 of the respondents from this group. They were asked to give reasons for the relative importance placed on factors in the questionnaire for pair-wise comparison and the current situation of environmental issues in Sri Lankan infrastructure projects. This information helped to supplement the survey results.

The focus of the present study is ERSs and, as explained in Sections 3.4.1 and 3.7.2, respectively, it is important for ERSs to be comprehensive and to address the life-cycle of a project when covering the environmental impacts of the selected project type. Therefore, in Step 3, for the purpose of identifying the environmental problems and positive environmental impacts of Sri Lankan SHP projects, interviews of the public in the vicinities of the SHP projects were carried out. The respondents were selected carefully to obtain reliable data and, more often than not, those interviewed as representatives of the general public were school principals, teachers and village officers in order to obtain a fair and balanced view of issues. While some of them were from villages in the locality, others were outsiders who had spent many years in the locality. They were asked open-ended questions about their experiences and ideas as well as the general public opinion regarding the impacts of SHP projects in the area.

Other published information and data such as EIA and IEE reports on SHP projects were also referred, which were available in the Central Environmental Authority (CEA), Sri Lanka library. Furthermore, newspaper articles regarding SHP projects were referred considering them as a conduit for public perception. Data on environmental impacts were collected until the list of impacts reached the point of redundancy, that is, the point at which data collection does not lead to the discovery of additional factors (Scavarda et al., 2004; Armstrong, 2005) as shown in Figure 9.1 and the Table 9.1. Since this study used the snowball sampling method, the point of redundancy is applicable to this study (Armstrong, 2005).

The number of experts working on environmental issues in the Sri Lankan SHP sector is limited to a small group. The same group of experts is thus involved in the EIA procedure, monitoring, consultation and so on. Since some developers operate several SHP projects, they employ environmental managers to handle the environmental issues in the SHP projects. Thus, a group consisting of 11 experts in the Sri Lankan SHP sector was selected deliberately to participate in Step 3 mentioned in the research process. The list of issues identified in the SHP projects was presented to this group. After several rounds of discussions with this group, the solutions for environmental problems were determined and the list of factors that should be considered in assessing SHP projects was validated and finalized for further analysis.

7.7. Data Collection

According to Step 2 in the research process (Figure 7.1), in order to measure the relative importance of the factors presented in the conceptual framework (Figure 6.15), a pair-wise comparison was employed using a structured questionnaire (Appendix-1). Before they responded, the factors under consideration were explained to the sample group in order to avoid misunderstanding and to ensure the reliability of the data. Some of the factors related to positive impacts and hence measured the importance of implementing these positive impacts. On the other hand, some of the factors related to negative impacts and, hence, measured the severity of those impacts in order to determine the relative importance of minimising such impacts. Therefore, the questions were structured in such a way as to facilitate pair-wise comparisons of environmental problems and positive environmental impacts. Some factors took two different forms in the questionnaire as shown in the example given in Table 7.1. Here, "Waste Disposal" (ES4) appears as a problem in comparison with the severity of other problems. When it is compared with positive impacts, the importance of "Minimising Waste Disposal" (ES4) is measured. All the questions were structured in that fashion to enable meaningful comparisons.

Table 7-1: Sample Questionnaire for Pair-wise Comparison

<table>
<tr><td colspan="17">Compare the severity of the problems of Sri Lankan infrastructure projects, which threaten environmental sustainability, which are shown below.</td></tr>
<tr><td colspan="8">Waste disposal issues (ES4)</td><td colspan="9">Less attention to environment due to poverty (ES7)</td></tr>
<tr><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td></tr>
<tr><td colspan="17">Compare the importance of factors given below in order to achieve the environmental sustainability of Sri Lankan infrastructure projects.</td></tr>
<tr><td colspan="8">Minimising waste disposal (ES4)</td><td colspan="9">Minimise usage of materials (ES2)</td></tr>
<tr><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td></tr>
</table>

According to Step 4 in the research process (Figure 7.1), it was required to measure the relative importance of the identified environmental issues in SHP projects. First, the list of impacts was validated through interviews with environmental experts in the SHP sector as explained in Section 7.6. Each impact was discussed for its relevance to assessment and solutions were sought. The list of identified environmental issues of SHP projects was then compiled to illustrate the impacts at each stage as presented in the Table 9.3. The group of experts were asked to simply mark the chart as shown in Appendix-2 in order to identify under which ES factors these impacts and solutions should be included. All the marked factors were included under relevant ES factors accordingly. Since there were several solutions for some problems, they were arranged at hierarchical levels as illustrated in Figure 9.14.

Based on this hierarchical structure, a questionnaire (Appendix-3) was developed. This questionnaire was used in the final round of interviews to rank the importance of factors in a pair-wise comparison with the same group of experts. Using the same group of experts ensured that the experts were familiar and well understood the issues that were included in the questionnaire and, hence, that the responses were reliable. With the first rounds of discussion, the criteria (qualitative data) were determined and with the questionnaire survey, weightings (quantitative data) were determined by the same group of experts.

7.8. Choice of Data Analysis Technique

The study required weights to be assigned to each factor in the framework, thus reflecting the relative importance of each factor for assessing the environmental sustainability of infrastructure projects in Sri Lanka. The same technique was applied when the factors of SHP projects were analysed. Analytic Hierarchy Process (AHP) was selected as the data analysis technique to best fit this requirement taking into consideration the factors explained below.

7.8.1. Relative Measurements

The purpose of Step 2 in the research process was to measure the importance of each factor in the framework towards achieving environmental sustainability of the infrastructure projects. This is because there are limited resources available financially or physically in a project and that they should therefore be allocated judiciously between the most important and least important requirements. With regard to the environmental sustainability of a project, the most severe problems must necessarily be addressed first while the others that are lower in the scale of severity would be addressed later depending on the availability of resources.

As explained in Section 3.6.7, absolute measures are useful for ERSs if available. The section also mentioned that if the global carrying capacities are known, the measures can be based on such data. However, the absolute measures of natural capital stocks or the severity/importance of environmental issues are not sufficiently available yet. Moreover, not only are the carrying capacities not defined but sometimes it is not possible to define them. Although some attempts to do this are already underway, the process of measuring and valuing the natural capital stock has a long way to go.

If it is possible to measure or value the natural capital stock with a single unit, or to know the natural growth rate and depletion rate of all natural resources, then it would be possible to decide which natural resource needed to be preserved more and to what extent. According to Saaty and Vargas (2006), it is highly unlikely that people would ever find ways to measure everything on a physical scale with a unit. Hence, the ERSs would still need to depend on expert opinion as shown in Section 3.6.7.

One needs eyes and sometimes even hands to estimate how many times one object is larger than another (Saaty, 1994). However, when people deal with intangibles, as they do all the time, they must rely on their feelings instead of their senses in order to make the comparison. The facility to make comparisons based on feelings and to interpret in terms of experience appears to be an intrinsic ability of consciousness (Saaty, 1994). If this facility were to be operationalized, mathematically, these feelings express how much more an attribute is possessed by one element than by another taken as the unit (Saaty, 1994). Hence, it also provides ratio-scale measurements which can be attributed to a single unit for meaningful comparisons. These relative measurements form the base for weightings in the ERSs. It suggests that the projects that address severe problems can score more points in the ERSs. AHP analyses data with ratio- scale measurements.

7.8.2. Scale of Measurement

It is common to use linear ranking methods such as the ‘Likert’ scale in measuring the significance of factors but the practice has not escaped criticism (Kendrick and Saaty, 2007). For example, if one were to compare A and B, where one respondent were to give “very important” or “5” in the scale to both the factors of A and B, it may not really mean that A and B are equally important. Moreover, in such a measurement, the factors A and B are not compared for their significance. In order to overcome some of the weaknesses of linear ranking methods such as the ‘Likert’ scale, a pair-wise comparison was employed in this study. Paired comparisons of tangibles or intangibles can be used to create a ratio scale of absolute numbers which represent their “strength” (Saaty, 1994).

When the pair-wise comparison is used with a measurement of scale, it measures the importance of one factor against another as well as how many times. The final figures thus give more reliable measurements for relative importance with meaningful weightings. For instance, it compares the importance of A and B and measures how many times A is important over B and vice-versa. AHP provides a systematic analysis of factors using relative measurements with pair-wise comparisons on a fundamental scale.

7.8.3. Nesting Principle and Hierarchical Structure

The study adopted an approach similar to the one explained in Section 3.8.2, to determine the criteria and sub-criteria of ERSs in a hierarchical manner. A problem-solution approach with several hierarchical levels was used to identify the environmental issues in SHP projects under each ES factor and sub-factor in the conceptual framework while the relative importance of each issue under each ES factor was weighted. AHP deals better with problem-solution approaches that have hierarchical levels.

7.8.4. Small Sample Group

As stated in Section 7.6, the number of experts working on environmental issues in the Sri Lankan SHP sector is limited. Consequently, the sample size in the study is smaller but representative. Since most statistical methods demand a large sample group, the study opted for AHP because, according to Kim and Kim (2009), the sample size is not critical in the AHP analysis, as it can provide meaningful results even with a small sample, if the representativeness of the sample is secured.

7.9. Analytic Hierarchy Process (AHP)

AHP is a structured method for decision-making and problem-solving where the decisions are complex, unstructured and multiple-attribute, and where at least some of the decision variables or decision attributes are qualitative and cannot be directly measured (Partovi, 1992; Saaty and Vargas, 2001; Massaeli, 2011). It was originally developed by Thomas L. Saaty during the 1970s and met with almost immediate acceptance. Since its inception, AHP has been applied in a wide variety of decision areas (Partovi, 1992; Massaeli, 2011). For instance, it has been used for benchmarking activities in manufacturing processes (Partovi, 1992) in order to evaluate alternatives to sub-components and parts in product design that satisfy customer, technical, and financial requirements (Akgunduz, 2002); as a systematic decision-making tool by operation managers in order to solve the most important bottlenecks of production processes (Massaeli, 2011), and many more.

Partovi (1992) stated several advantages of using AHP: better communication leading to clearer understanding and consensus among the members of decision-making groups, resulting in turn in a greater commitment to ranking elements and to selecting alternatives. Among different decision areas, the current study requires benchmarking of a set of factors. Hence, AHP is used to benchmark environmental issues that should be considered in ERSs.

Saaty (2008) explained the basic steps in AHP analysis as follows:

- Define the problem and design the hierarchy;

- Prioritization procedure; and
- Calculations of results.

Define the problem and design the hierarchy

In the first step of AHP, unstructured decisions are disintegrated into components and arranged in a hierarchical order. The simplest form of hierarchy consists of three levels: respectively, the goal or the overall objective of the decision at the top level; elements affecting the decision which are called ‘criteria’ in the intermediate level; and decision options or ‘alternatives’ in the lowest level. These basic hierarchical levels are presented in Figure 7.2.

The hierarchy does not have to be complete, that is, an element at the intermediate level is not required to function as a criterion for all elements in the lowest level. Thus, a hierarchy can be divided into sub-hierarchies (Partovi, 1992; Saaty and Vargas, 2001**)**. Between Levels 3 and 4, there may be several levels to break down the issues into several levels of sub-criteria.

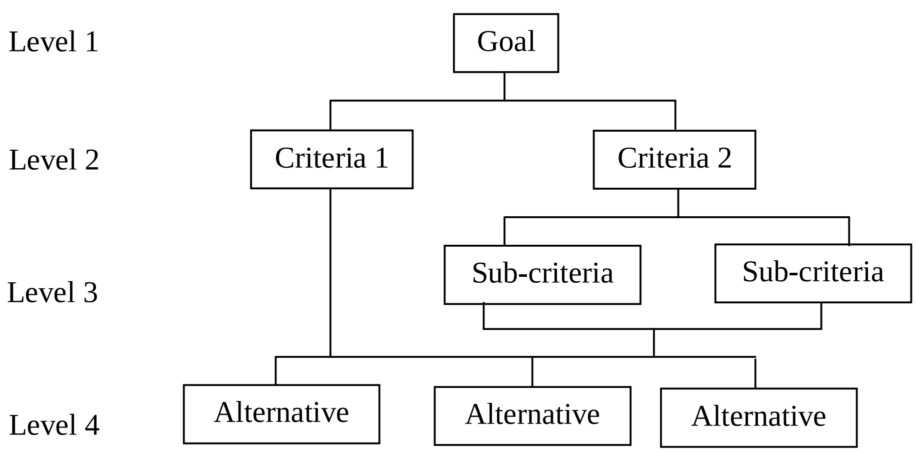

Figure 7-2: Basic Hierarchy in AHP

In the current study, the goal or overall objective is environmental sustainability in infrastructure projects which is the topmost level. The second level comprises eight main criteria (ES factors) with some of them divided into sub-criteria (for example ES1a and ES1b). Environmental issues are considered under each main criterion and sub-criterion. The alternatives or the lowest level are not considered in the current study. This is because this level contains the decision options to be selected based on the upper level priorities. All the elements in this level should be linked with the immediate upper-level criteria or sub-criteria to complete the hierarchy. However, in this study, project options/alternatives are not considered though they provide the means to select or calculate the scores of project options/alternatives. Moreover, not all the lowest level elements are linked to the immediate upper level; hence, the hierarchy contains only up to sub-criteria level (Level 3 as shown in Figure 7-2). Since this study develops a conceptual framework to assess the environmental sustainability of infrastructure projects, it used AHP to determine the criteria and weightings for benchmarking but not for the benchmarking exercise itself. A study conducted by Partovi (1992) used AHP for a similar purpose in order to select the production activities for benchmarking with only up to Level 3 in the hierarchy.

Prioritization Procedure

Once the hierarchy is constructed, the prioritization procedure can be carried out to determine the relative importance of the elements in each level. This involves a pair-wise comparison with respect to their importance to an element in the next top higher level. Prioritization is to start from the top of the hierarchy and work downward by creating a number of square matrices called preference matrices in the process of comparing elements at a given level. A questionnaire can be prepared according to the completed hierarchy and the respondents can be asked to express their preference between every two elements against the higher level elements which they are linked to. They are functioning using a fundamental scale as presented in Table 7.2. These descriptive preferences can be presented in numerical ratings as in 1, 3, 5, 7 and 9, respectively, with 2, 4, 6, and 8 as intermediate values for compromises between two successive qualitative judgements (Saaty, 2008).

Table 7-2: The Fundamental Scale for AHP

Intensity of Importance	**Definition**	**Explanation**
1	Equal Importance	The two activities contribute equally to the objective.
2	Equal to moderate	
3	Moderate Importance	Experience and judgment slightly favour one activity over another.
4	Moderate to strong	
5	Strong Importance	Experience and judgment strongly favour one activity over another.
6	Strong to strong	
7	Very strong importance	An activity is favoured very strongly over another.
8	Very strong to extreme	
9	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation.

Source: Saaty and Vargas (2001)

Calculations of Results

Preference matrices obtained through prioritization can then be used to derive relative weights for the various elements computed as the components of the normalized eigenvector associated with the largest Eigen value of their comparison matrix. In the current study, spreadsheets developed by Goepel (2013) were used for the computation. The spreadsheets provide a user-friendly interface when handling multiple questionnaires and dealing with adjustments. If any sub-criteria are categorized under more than one main criterion, final weights can be calculated as a summation of weights obtained by each sub-criterion as has been done by Partovi (1992) in selecting production activities for benchmarking.

7.10. Validity and Reliability of Data

The sample size in the field survey was determined by point of redundancy to uncover the maximum possible number of environmental issues in SHP projects. Identified impacts were validated through several rounds of discussion with a group of experts in the field.

AHP measures the degree to which the pair-wise comparisons are consistent with a measure. This measure is called the consistency ratio (CR). It will detect inadvertent misjudgements in comparisons (Partovi, 1992) and, hence, ensure the reliability of the data collected. A consistency ratio of 0.10 shows that the elements compared had a 10% chance to be purely random. If the CR is larger than 0.10, re-evaluation of the comparisons is recommended since some of the judgements are contradictory. Spreadsheets calculate CR and indicate the three most inconsistent judgments in each individual judgement set and allow adjustments (Goepel, 2013).

The weights are consistent if they obey the transitivity rule, that is $a_{ik} = a_{ij}.a_{ik}$ for all i, j, and k. Such a matrix might exist if the a_i is calculated from exactly measured data.

Then find a vector ω of order n such that $A\omega = \lambda\omega$. For such a matrix, ω is sai d to be an eigenvector (of order n) and λ is an eigenvalue. For a consistent mat rix, $\lambda = n$. For matrices involving human judgment, the condition $a_{ik} = a_{ij}.a_{ik}$ does not hold as human judgments are inconsistent to a greater or lesser degree. In such a case, the ω vector satisfies the equation $A\omega = \lambda_{max}\omega$ and $\lambda_{max} \geq n$. The difference, if any, between λ_{max} and n is an indication of the inconsistency of judgments. If $\lambda_{max} = n$, then the judgments have turned out to be consistent. Finally, a Consistency Index (CI) can be calculated from $(\lambda_{max} – n)/(n-1)$.

The CI needs to be assessed against judgments made completely at random. Saaty (2001) provided large samples of random matrices of increasing order and the CI of those matrices. The true CR is calculated by dividing the CI for the set of judgments by the Index for the corresponding random matrix. Saaty

(2001) suggested that if that ratio exceeds 0.1, the set of judgments may be too inconsistent to be reliable. If CR equals 0, that means that the judgments are perfectly consistent. CI is divided by the corresponding value from large samples of matrices of purely random judgments using the Table 7.3. The upper row is the order of the random matrix, and the lower is the corresponding index of consistency for random judgments.

Table 7-3: Random Matrices

1	2	3	4	5	6	7	8	9	10
0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Source: Saaty (2001)

7.11. Summary

This chapter presented the research design and methodology including sampling, data collection, data analysis, and validity and reliability of data. A combination of purposive and snowball sampling was used in the study since certain attributes had to be representative and more respondents had to be found through referrals. Considering the need for relative measures, scale of measurement, hierarchical levels, and the small sample group, AHP was selected to analyse data and assign weightings to factors in the conceptual framework for ERSs. AHP provides consistency calculations to ensure the credibility of results.

Chapter 8: Data Analysis and Results

8.1. Introduction

The chapter presents the analysis of the survey data on the factors for assessing the environmental sustainability of Sri Lankan infrastructure projects using the AHP technique. It presents the relative importance of each factor in the conceptual framework and highlights the key results. The chapter also presents the findings of the interviews with experts in the infrastructure sector. These interviews were based on in-depth explorations of the survey responses in order to supplement the survey results. The chapter then presents the conceptual framework for ERSs for assessing infrastructure projects in Sri Lanka including the factors and relative importance of those factors. The chapter also presents the validation of the proposed conceptual framework.

8.2. Survey Data Processing

8.2.1. Incomplete Judgments

There were incomplete judgements for pair-wise comparisons in the questionnaires. This can be due either to missing judgements or to the fact that the respondent may not have formed a strong opinion on that particular judgement. However, when employing the AHP technique, incomplete judgements do not impact the results if the minimum number of comparisons required is achieved. For example, Carmone et al. (1997) referred to a Monte-Carlo simulation study which demonstrated that deleting as much as 50% of the comparisons would not lead to a significant difference in results. According to the literature on the AHP technique, the minimum number of comparisons required is $n-1$, one for each row or column of the pair-wise comparison matrix (Ishizaka and Labib, 2011). This would leave at least one path for calculating other incomplete judgments (Harker, 1987). The rest of the comparisons are useful for checking consistency, and possibly improving accuracy (Ishizaka and Labib, 2011). Therefore, the respondents were not asked again to fill in the incomplete judgements because the AHP literature offers logical methods to calculate such missing judgements rather than forcing participants to give vague responses that deduce opinions not strongly formed or waiting for responses that are not forthcoming, which would delay the data processing.

A simple method was proposed by Harker (1987) to calculate incomplete judgements. This method is based on the transitivity rule in AHP where, subject to the matrix being perfectly consistent, the condition below holds for all the comparisons where a_{ij} is the comparison between criteria i and j.

$$a_{ij} = a_{ik} . a_{kj}$$

For example, if X is twice as important as Y and if Y is three times as important as Z, then it is expected under the transitivity rule that X is six times (3x2=6) as important as Z. However, this is seldom the case because human judgments can be inconsistent by nature. This issue is addressed in AHP technique under consistency and consistency will be tested for all the judgments for the required consistency level before the analysis.

In this method, Harker (1987) explained that the incomplete elements in the matrix can be filled by using the geometric average of intensities of all the indirectly calculated comparisons. These are the intensities of all the possible elementary paths connecting i and j. That is, the judgment a_{ij} is the average of all the possible ways in which i and j can be judged by considering their relationship with intermediate attributes or nodes. If the incomplete judgments in the matrix are perfectly consistent, then every elementary path from i to j must have the same intensity. However, due to inconsistencies in human judgements by nature, the intensity of each path may differ. Therefore, an average of these path intensities is used. However, this average is not the arithmetic but the geometric mean as is used for combined judgment calculations. According to Harker (1987), since each path intensity can be treated as a separate judgment in a set of group judgments, the geometric mean of the path intensities must be used to synthesize this information to yield a_{ij}.

Ishizaka and Labib (2011), however, pointed out a drawback of this method which is the long processing time required when the number of criteria and missing judgements grow. However, only 39 comparisons were required in this study and there were not many incomplete judgments in the questionnaires. Therefore, Harker's method (1987) was used in this study.

8.2.2. Improving the Consistency of Judgements

As also stated earlier, the spreadsheets by Goepel (2013) indicated the three most inconsistent judgements by each respondent. Inconsistency measures compare the individual judgments (a_{ij}) with the corresponding eigenvector (w_i/w_j). Therefore Saaty (1994, p. 92) provided an adjustment method to improve the consistency of judgments. This method was used to adjust each respondent's set of judgments by looking at the consistency ratio of each set of judgments. The adjustment is to change a_{ij} into w_i/w_j for the particular inconsistent judgment. This method was applied to top most inconsistent judgements indicated in the spreadsheet until the consistency ratio reached below 10%. It does not change the results significantly but improves the consistency and therefore ensures the reliability of the data set. The method was applied to each respondent's set of judgments and the adjusted sets were used for the AHP analysis and final calculations.

8.3. AHP Calculations – Relative Importance of ES Factors

8.3.1. Analysis of Main Factors

After completing the judgments and adjusting for consistency as explained in Section 8.2.2, the data were used in AHP calculations. Table 8-1 shows the values for the combined responses of each pair of comparisons. The results are graphically represented in Figure 8-1. These values are the geometric means of individual responses. Since the comparisons result in ratio scale data, AHP uses the geometric mean instead of the arithmetic mean (Saaty, 2001). The normalized weight for each ES factor and sub-factor has been calculated using the calculation process explained by Saaty (2001). The complete calculation process is illustrated in Appendix-4. Then the values were tested for consistency as per the below calculations.

Consistency Ratio (CR) = CI/RI

λ max = 8.03> 8 (number of factors) means no errors in the calculations and values can be used to calculate the Consistency Index (CI).

Consistency Index (CI)	=	(λmax - n)/(n - 1)
	=	(8.03 – 8)/(8-1)
	=	0.0048

RI = 1.40 (from random matrices table for N= 8) (see Table 7-3)

Consistency Ratio (CR)	=	0.0048/ 1.40
	=	0.0035< 0.1

CR < 0.1 means the values are consistent at 10% random values and that the results are accepted as consistent.

The factor "Conserving Biodiversity" (ES6) received the highest score of 19.1% among eight main factors considered. The factor addressing "Waste Disposal" (ES4) issues and issues related to "Usage of Non-renewable Energy Sources" (ES3) received the second and third highest scores of 18.8% and 17.0% respectively. These three main factors had only slight differences in scores indicating that all three factors carry the highest importance with regard to addressing ERSs assessing infrastructure projects in Sri Lanka. Issues related to "Usage of Materials (renewable)" (ES2) and "Investing in Natural Capital" (ES5) received almost equal scores of 10.4% and 10.2% respectively. Issues related to "Land Use" (ES1) received the fifth score of 9.2%, which was only slightly lower than the scores for factors ES2 and ES5. Factors addressing "Contributions to Eradicate Poverty" (ES7) and "Avoid Corruption" (ES8) issues received the final two rankings with scores of 7.5% and 7.9% respectively.

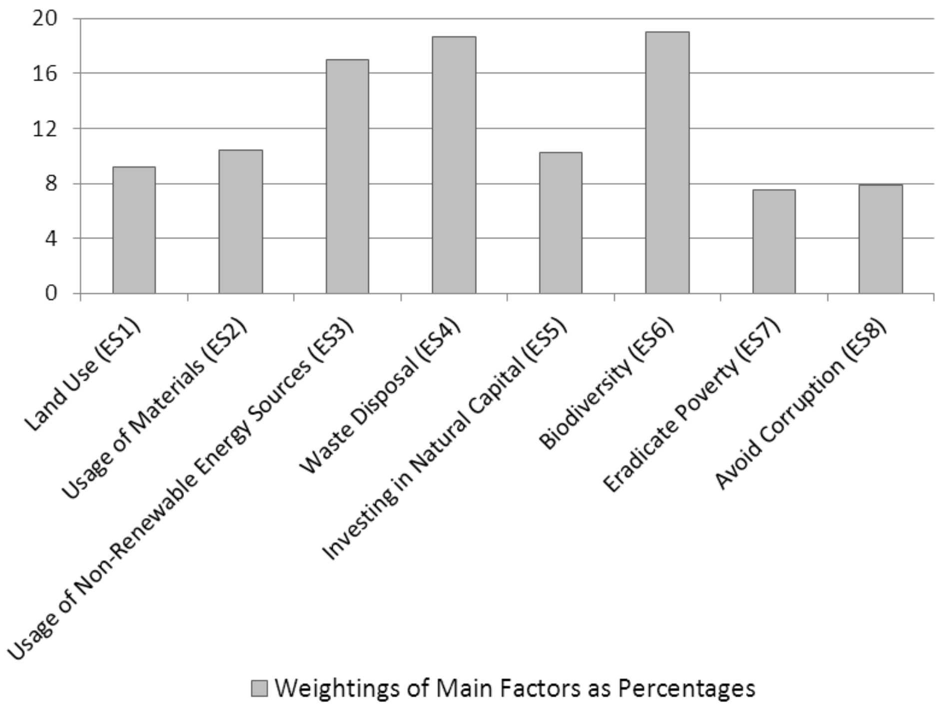

Figure 8-1: Weightings of main ES Factors

8.3.2. Analysis of Sub-Factors

<u>Sub-factors of Land Use (ES1)</u>

Two sub-factors were considered under “Minimizing Land Use” (ES1): the “in terms of area” (ES1a), which addresses the importance of minimizing land take for infrastructure projects, and the “in terms of damages to land composition” (ES1b), which addresses the importance of preventing the damages to land composition. This is because, even within the same area utilized, the damages to land composition can be different, which in turn leads to a difference in environmental performance. The survey results revealed that considering the composition issue is of higher importance (0.056) than the area issue (0.035) as shown in Table 8-2.

Table 8-1: AHP Calculations – Normalized weights and λ max for Consistency

	ES1	ES2	ES3	ES4	ES5	ES6	ES7	ES8	Normalized Weight	%	Aω =λmaxω	λ max	Rank
ES1	**1.00**	1.05	0.50	0.49	0.90	0.40	1.23	1.25	**0.092**	9.2	0.74	8.03	6
ES2	0.95	**1.00**	0.58	0.67	1.05	0.53	1.48	1.31	**0.104**	10.4	0.84	8.03	4
ES3	2.01	1.72	**1.00**	0.90	1.67	0.88	2.16	2.07	**0.170**	17.0	1.37	8.03	3
ES4	2.06	1.50	1.12	**1.00**	1.56	1.04	3.05	2.53	**0.188**	18.8	1.51	8.04	2
ES5	1.11	0.96	0.60	0.64	**1.00**	0.61	1.19	1.10	**0.102**	10.2	0.82	8.03	5
ES6	2.50	1.87	1.14	0.96	1.64	**1.00**	2.43	2.45	**0.191**	19.1	1.53	8.04	1
ES7	0.81	0.67	0.46	0.33	0.84	0.41	**1.00**	0.96	**0.075**	7.5	0.60	8.03	8
ES8	0.80	0.76	0.48	0.40	0.91	0.41	1.05	**1.00**	**0.079**	7.9	0.64	8.03	7
									Total = 1.000	100%		Average = 8.03	

Table 8-2: Weightings of Sub-factors of Land use (ES1)

	Area (ES1a)	Composition (ES1b)	Normalized weight	ES1 weight	Final weight
Area (ES1a)	**1.000**	0.625	0.385	0.092	**0.035**
Composition (ES1b)	1.599	**1.000**	0.615	0.092	**0.056**
			1.000		0.092

Sub-factors of Materials Usage (ES2)

Three sub-factors were considered under "Minimizing Usage of Materials" (ES2): the importance of minimizing the usage of materials "In terms of quantity" (ES2a), "In terms of impacts during extraction of materials" (ES2b), and "In terms of impacts during the usage of materials" (ES2c). While ES2b addresses issues related to the source of materials and extraction methods, ES2c addresses issues of harmful materials including harmful usage. This is because, even with the same quantity of materials utilized, the damage at the extraction point and harmful usage can lead to a difference in effect with regard to the environment. Survey results revealed that ES2b is of higher importance (0.041) than ES2c (0.034) and ES2a (0.030), respectively, as shown in Table 8-3. Since there were more than two factors under ES2, consistency was tested and it showed CR to be below the accepted level at 0.1.

Table 8-3: Weightings of Materials Usage (ES2) Sub-factors

	Quantity (ES2a)	Extraction (ES2b)	Harmful Usage (ES2c)	Normalized Weight	λ max	ES2 Weight	Final Weight
Quantity (ES2a)	**1.000**	0.747	0.843	0.283	3.02	0.104	**0.030**
Extraction (ES2b)	1.338	**1.000**	1.292	0.396	3.02	0.104	**0.041**
Harmful Usage (ES2c)	1.187	0.774	**1.000**	0.321	2.97	0.104	**0.034**
				1.000	3.00		0.104

λ max = 3.00=3 (number of factors) means that there are no errors in the calculations and CR = 0.00 (CR < 0.1 means that the values are consistent at 10% random values).

Sub-factors for Usage of Non-renewable Energy (NRE) Sources (ES3)

As in the previous section for ES2, three sub-factors were considered under the "Minimizing Usage of NRE Sources" (ES3). The survey results revealed that minimizing "In terms of quantity" (ES3a) is of the highest importance (0.066) followed by the importance of minimizing the "Impacts during extraction" (ES3b) (0.054) and "Impacts during usage" (ES3c) (0.049), respectively, as Table 8-4 shows. Since there are more than two factors under ES3, consistency was tested and CR was found to be below the accepted level at 0.1. It should be noted that these results were different from those related to the usage of materials considered under ES2 where the "Damages during extraction" (ES2b) was the most important issue followed by "Damages during usage" (ES2c) and "Minimizing usage in terms of quantity" (ES2a), respectively, in order of importance.

Table 8-4: Weightings of Usage of NRE Sources (ES3) Sub-factors

	Quantity (ES3a)	Extraction (ES3b)	Harmful Usage (ES3c)	Normalized Weight	λ max	ES3 Weight	Final Weight
Quantity (ES3a)	**1.000**	1.193	1.388	0.391	2.99	0.170	**0.066**
Extraction (ES3b)	0.839	**1.000**	1.060	0.318	3.02	0.170	**0.054**
Harmful Usage (ES3c)	0.721	0.944	**1.000**	0.291	2.99	0.170	**0.049**
				1.000	3.00		0.170

λ max = 3.00=3 (number of factors) means that there are no errors in the calculations and CR = 0.00 (CR < 0.1 means that the values are consistent at 10% random values).

Sub-factors of Waste Disposal (ES4)

Three sub-factors were considered under “Minimizing Waste Disposal Issues” (ES4): the importance of minimizing waste disposal “In terms of quantity of waste disposed” (ES4a), considering the “Quality of waste before disposal” (ES4b) and the “Location of waste disposal” (ES4c). This is because even with the same quantity of waste disposed, the environmental damages can be different depending on the quality of waste and the location at which the waste is disposed. According to the survey results, ES4b and ES4c possess almost identical importance (at 0.071 and 0.072 respectively), which is noticeably higher than that for ES4a (at 0.044) as Table 8-5 shows. Since there are more than two factors under ES4, consistency was tested and CR was found to be below the accepted level at 0.1.

λ max = 3.00=3 (number of factors) means that there are no errors in the calculations and CR = 0.00 (CR < 0.1 means that the values are consistent at 10% random values).

Table 8-5: Weightings of Sub-factors under Waste Disposal (ES4)

	Quantity (ES4a)	Quality (ES4b)	Location (ES4c)	Normalized Weight	λ max	ES4 Weight	Final Weight
Quantity (ES4a)	**1.000**	0.650	0.595	0.237	3.00	0.188	**0.044**
Quality (ES4b)	1.538	**1.000**	1.014	0.378	3.04	0.188	**0.071**
Location (ES4c)	1.680	0.986	**1.000**	0.385	2.97	0.188	**0.072**
				1.000	3.00		0.188

Sub-factors of Investment in Natural Capital (ES5)

Two sub-factors were considered under “Investing in Natural Capital” (ES5): the investment “To maintain natural capital stock” (ES5a) and the investment “To enhance natural capital stock” (ES5b). The survey results showed that the investment “To maintain natural capital stock” (ES5a) is of higher importance (0.058) than the investment “To enhance natural capital stock” (ES5b) (0.043) as shown in Table 8-6.

Table 8-6: Weightings of Sub-factors of Investment in Natural Capital (ES5)

	To Maintain (ES5a)	To Enhance (ES5b)	Normalized Weight	ES5 Weight	Final Weight
To Maintain (ES5a)	**1.00**	1.35	0.575	0.102	**0.058**
To Enhance (ES5b)	0.74	**1.00**	0.425	0.102	**0.043**
			1.000		0.102

As shown in Table 8-7, the final weightings of sub-factors were calculated by multiplying the normalized weighting of sub-factor by the weighting of the relevant main ES factor. This means that weightings under each main factor are distributed among its sub-factors in the hierarchy. Therefore, in each level, the sum of weightings is equal to 1.00 as shown in Figure 8-2.

Table 8-7: Results of AHP Analysis

Main Factors (Level 1)	**Normalized Vector Weight (Xn)**	**Sub-factors (Level 2)**	**Normalized Vector Weight (x_n)**	**Final Weighting (Xn)* (x_n)**
ES1	0.092	ES1a ES1b	0.385 0.615	0.035 0.056
ES2	0.104	ES2a ES2b ES2c	0.283 0.396 0.321	0.030 0.041 0.034
ES3	0.170	ES3a ES3b ES3c	0.391 0.318 0.291	0.066 0.054 0.049
ES4	0.188	ES4a ES4b ES4c	0.237 0.378 0.385	0.044 0.071 0.072
ES5	0.102	ES5a ES5b	0.575 0.425	0.058 0.043
ES6	0.191			0.191

ES7	0.075			0.075
ES8	0.079			0.079
Total	**1.000**			**1.000**

8.4. Findings from Interviews and Other Observations on ES Factors

As explained in Section 7.6, interviews were carried out with 18 experts who undertake environment-related work in the infrastructure and development sectors in Sri Lanka. The details of their level of experience and education are summarized in Table 8-8.

Table 8-8: Profiles of Interviewees

No.	Specific Sector and Career	Highest Academic Qualification Achieved	Experience in the Field (years)
1	Development Administration – Environmental Consultant	MSc in Environmental Economics	20
2	Infrastructure Investment – Environmental Manager	BSc	15
3	Development Administration – Environmental Consultant	MSc in Urban Environmental Management	25
4	Development Planning – Environmental Officer	MSc in Town and Country Planning	34
5	Road Development - Environmentalist	MSc in Integrated Water Resource Management	6
6	Administration of Environmental Programs – Environmental Program Manager	MSc in Public Management	2
7	Forestry Conservation – Environmental Manager	MSc	6
8	Wildlife Conservation - Environmental Manager	MSc in Environmental Management and Forestry	14
9	Administration of Environmental Compliances – EIA Expert	MSc	20
10	Irrigation Development – Environmental Consultant	Postgraduate Diploma	33

11	Environmental Services - Environmentalist	MSc in Environmental Science	10
12	Road Development – Environmental Manager	MSc in Engineering	30
13	Administration of Environmental Programs – Environmental Manager	MBA	5
14	Irrigation Development – EIA Expert	BSc	17
15	Administration of Environmental Programs – Environmental Manager	MSc	26
16	Building Research - Environmentalist	MSc in Environmental Science and Technology	25
17	Land Development – EIA Expert	Dip in Environmental Science and Technology	15
18	Development Planning – Environmental Manager	MSc in Architecture	30

8.4.1. Minimizing Land Use (ES1)

Although not reflected as much in the survey results, "Minimizing Land Use" (ES1) received more attention in the interviews. The reason could be that land use issues are more apparent in the infrastructure development and that therefore experts are more concerned with it. In Sri Lanka, currently, infrastructure development is booming and spreading all over the country, including rural and undeveloped areas. On the other hand, with the declarations of the Forest Department and National Physical Planning Department on land reservations for conservation purposes, only a limited amount of land is available for development activities. Hence, land in Sri Lanka is no longer an unlimited resource and land shortages can be experienced in the near future. In case of land shortages, increasing number of construction projects in the country can be spread towards ecologically sensitive areas as well and cause damages to the land compositions. Therefore, contemporary development activities should heed this issue. As Interviewee 17 stated:

"Land area shortage is severe especially in urban areas. Also increased development projects all over the country that employ large land areas

have created problems of damaging the land composition. Also there are concerns to maintain green cover of the country and the areas available for development projects are getting lesser and lesser. However, the development projects are inevitable and hence, it is better to start thinking of land shortages in the country as a whole and efficiently use land when locating and designing infrastructure projects."

Interviewee 6 expressed a similar view and stated that:

"Deforestation will take place due to the projects carried out in rural areas because these areas have a majority of the country's vegetation cover. Although such areas are not yet dense with developmental activities and a land shortage issue is not yet experienced, with the increasing developmental trends, care should be taken to minimize land take and impacts to land composition in those areas."

The country's EIA process is mandatory only for certain projects as explained in Section 5.5, and this limitation causes significant environmental impacts in the infrastructure sector. As Interviewee 17 put it:

"The EIA procedure does not cover all the infrastructure projects but only prescribed projects. Therefore the land use and land composition problems are not adequately addressed under these legislations."

Moreover, the absence of a Master-plan in Sri Lanka for development activities, and lack of integrated planning between government bodies with regard to developmental activities were identified as major reasons for environmental and land issues. So Interviewee 9 pointed out that:

"Land use issues will be severe in the country with the increasing developmental trend, due to the lack of planning and the absence of a Master Plan."

Interviewee 10 also highlighted the same problem, giving as example the contradictory policies of the Mahaweli Authority of Sri Lanka (MASL) and the Forest Department with regard to land use:

> *"The absence of a Master Plan for development is a problem today. On one side, the Forest Department has declared ecologically sensitive areas and the balance areas as suitable for developmental activities. But these land areas are not sufficient to meet the current developmental needs. Also according to the current government's vision, one third of the country's land areas is targeted for vegetation cover. This seems an impossible target with land availability and forest declarations. For example, the 'Mahaweli Multipurpose Development' was planned before the Civil War and there was a master plan identifying forest reservations and lands for developmental activities. The Mahaweli Authority handed over the forest reservation areas to the Forest Department and Wildlife Department but now access to these areas is restricted even for maintenance work by the Mahaweli Authority. Likewise, the declarations under the Forest Department sometimes contradict developmental activities due to the absence of a Master Plan and lack of cooperation and coordination between the different Authorities."*

The lack of coordination between different government agencies and the absence of a Master Plan for developmental activities also lead to a repetitious cycle of construction and demolition in the infrastructure sector which, in turn, leads to unnecessary waste generation and excessive materials consumption. Therefore, experts recognized that the country needs efficient use of land areas rather than merely minimizing land take. Interviewee 12 emphasized this and provided an example from the road sector to support his position:

> *"Permanent land usage cannot be eliminated in developmental activities and there is a need for efficient usage of land rather than minimizing land take. Meeting future needs should be considered here. Otherwise future expansions may involve demolitions and further damage to land composition. For example, constructing narrow roads in some areas now means that expanding those roads in future would require the demolition of other manmade structures alongside the road. This means that the vegetation cover has to be cleared once again after sometime which cause damages to land composition."*

Interviewee 7 also stated that:

> *"In future, the area shortage can be a problem and hence, it is important to plan developmental activities wisely in the potential development site areas that have been identified".*

Interviewee 11 re-iterated as follows a very common issue experienced by those working in the Sri Lankan infrastructure sector due to lack of planning and coordination among government agencies with regard to land use:

> *"Over many years we know that roads are constructed first, then the telecommunication and water providers dig them up to lay the service lines. However, the reconstruction will not take place for a long time causing environmental issues and inconvenience to everyone. It is also a barrier to raise standards of living while causing unnecessary demolition and reconstruction works."*

Of the two different sub-categories under "Minimizing Land Use" (ES1), "Minimizing land area" (ES1a) and "Minimizing damages to land composition" (ES1b), the latter received higher priority (5.6%) than the former (3.5%) in the survey results. In the interviews, the respondents gave reasons for this preference as seen in the observations of Interviewees 14 and 4 respectively:

> *"Land usage will create many environmental issues in the near future due to current developmental trends because they are focused on less developed rural areas with many forest areas. Here the land composition should be considered more than the land area."*

> *"Damaging land composition is the severe issue compared to the shortage of land areas because the country is still not dense with developments. Infrastructure projects are required all around the country but not limited to a specific area. Therefore the damages to land composition should be considered in the first place when planning infrastructure development in ecologically sensitive areas."*

8.4.2. Minimizing Usage of Materials (ES2)

Most interviewees also noted that, there are indications of material shortage in the near future in the Sri Lankan construction sector. Interviewee 14 highlighted the need for more attention to this issue at the project level stating that:

> *"Although the problems of material shortages are not yet experienced severely, sand shortages are rising with current developmental activities. There is a need for alternatives to cope with future needs and some projects use washed excavated soil as an alternative to sand which can be considered under re-using. More innovations and alternatives are required and ERS can promote these at project level."*

According to Interviewee 5:

> *"There is a huge demand for sand and aggregate for construction and earth materials for land filling. This will create a material shortage in the near future and therefore careful usage too is important."*

Interviewee 1 also expressed a similar view regarding the prospect of materials shortage in the future and also noted an important aspect to sources of materials. According to him, the materials shortage is not felt as it should be because supplies are still continuing. However, these continuous supplies may be from unsustainable sources:

> *"Materials such as water, sand and aggregates are not considered as scarce materials in Sri Lanka. However, the current pattern of usage will be problematic for future consumption. Materials shortage in the country is not much experienced yet but it does not mean that there is no shortage. Still there are materials available but may be from unsustainable sources. However, in the near future, the materials shortage will be severe in Sri Lanka with the increasing developmental trend and construction activities. Sand and aggregates shortage problems will be encountered in the near future. Although the required materials are supplied sufficiently, that may be from unsustainable sources."*

As in the survey results, among different issues considered under "Minimizing Usage of Materials" (ES2), "Impacts during extraction of materials" (ES2b) was the most frequently mentioned factor in the interviews. Many interviewees highlighted the issue of unsustainable sources and destructive extraction patterns in Sri Lanka. As Interviewees 5 and 12 put it, respectively:

> *"Nowadays in Sri Lanka, considering issues of materials extraction is the most important aspect of materials usage because there are many illegal materials extractions from unsustainable sources using improper extraction methods."*

> *"Extraction methods and unsustainable sources are the most critical among the issues related to usage of materials."*

Sand mining, earth cutting for commercial use, extracting aggregate, rock blasting, and timber logging were the issues frequently noted by the interviewees. While some problems associated with extraction are due to inappropriate extraction techniques, others are due to unsustainable sources and illegal sources. Interviewee 1, for instance, highlighted the sand mining issue as follows:

> *"Damages during extraction are higher due to the extraction method. Sand mining is carried out using heavy equipment causing landslides while the mining of aggregates causes erosion and landslides in some areas due to less controlled methods."*

Interviewee 3 highlighted an issue requiring urgent attention at present in the Sri Lankan construction sector stating that:

> *"Sources of materials are unsustainable or sometimes illegal in many situations. For example, soil cutting for road filling and so on is heavily carried out these days but not all imported soil is from sustainable and legal sources. We can see that soil cutting is carried out in many locations where there are small steeps and hilly areas. The vegetation cover is completely destroyed in these areas and the adjacent lands are under the threat of landslides and soil erosion."*

The experiences of the researcher in Sri Lanka support the above observation. The researcher too observed how prevalent the practices of earth cutting and selling are among the general public, with many people in remote areas allowing soil suppliers to extract soil from their private lands, disregarding how that practice may place adjacent lands under risk of landslides and soil erosion. This is because the extractors do not employ proper methods, only creating enough sharp steeps to extract the maximum quantity of soil from the owner's land without considering the risk imposed on adjacent lands. Although the owners of neighbouring lands may subsequently take legal actions against those culpable, the damage to the environment is already done and irreversible.

Interviewee 6 highlighted similar problems noted during aggregate extraction and rock blasting:

> *"Aggregate extraction is a serious issue in some areas because extraction is carried out continuously over many years in some ecologically sensitive areas. For example, 'Korathota' and 'Dadigama' areas are ecologically sensitive areas that provide habitats for many species. Continuous extraction of aggregates in the area has flattened this hilly area as well as the large rock in the area destroying the habitats for many species. Many animals in the area are therefore moving to neighbouring villages and as a result they are subject to illegal poaching and this leads to losing of species and biodiversity in the area."*

Considering the urgent need to address the materials extraction issue, the interviewees highlighted the importance of addressing these issues in legislation as well as in the environmental assessments of Sri Lankan infrastructure projects. For example, Interviewee 18 stated that:

> *"Consideration is not properly given to the source of materials. Although there is legislation to control logging, sand mining and rock blasting, including issuing permits, the demand for sustainable sources at the project level is not at a satisfactory level. Therefore, it promotes materials extraction from unsustainable sources and even from illegal sources. It is*

beneficial if environmental assessments emphasize the need for supplies from sustainable material sources in Sri Lanka at the project level."

8.4.3. Minimizing Usage of Non-renewable Energy Sources (ES3)

In the interviews, more attention was placed on "Minimizing Usage of Materials" (ES2) in comparison with "Minimizing Usage of NRE Sources" (ES3). However, the survey results showed ES3 to be the third most important factor with ES2 as the fourth most important factor. The reason for the slight deviation in results can be the significant impacts experienced recently due to excessive materials usage on account of current developmental trends. As Interviewee 13 put it:

"The country's share in the global GHG emissions is not significant compared to developed countries as well as some other developing countries. Therefore there are no strict environmental policies to minimize the usage of non-renewable energy sources yet. Thermal power generation is required at this stage to meet the energy needs at affordable prices and the government visions and environmental policies are not designed to restrict this need. However, they are quite concerned about local impacts such as dense emissions in urban areas."

However, usage of non-renewable energy sources should receive attention as reflected in the survey results due to significant global impacts such as climate change. Though Sri Lanka still does not experience severe regional environmental impacts due to non-renewable energy usage, there is an increasing trend towards reliance on fossil fuel energy and, thus, consideration should be given in future projects to minimizing such usage. It is also important to keep in mind the global issue of exhaustion of non-renewable energy sources, something that is bound to affect energy use in Sri Lanka as well. Highlighting these issues, Interviewee 4 stated that:

"Usage of non-renewable energy sources is increasing in the country due to the increased number of thermal power plants, but from an environmental perspective, it is a global issue rather than a local issue. Because once exhausted, there will not be any more of the resource. Hence,

there are no solutions other than minimizing the quantity of usage. Of course, the severity of usage of these resources is less in comparison with other environmental problems in the country".

In Sri Lanka, currently, there is more focus on reducing the cost of fossil fuel usage rather than with reducing the cost to the environment resulting from its usage. Thus, the consideration of the source in particular is driven by price rather than by either its quality or its impact on the environment. However, the interviewees proposed that, as usage increases, it is good to consider environmental issues too in terms of the quality of resource and source of extraction through environmental assessment. Interviewee 1 stated that:

"Sources of non-renewable energy are not as much considered from an environmental perspective but mostly it is decided based on price. Sometimes the sustainable sources are expensive and not affordable. However, with the increasing usage of non-renewable energy sources, it is better if we can consider the source too in environmental assessments."

8.4.4. Minimizing Waste Disposal (ES4)

One third of interviewees stated that waste disposal is the most severe environmental problem facing the country today. However, they stated that this is due to all types of waste with domestic waste in urban areas in particular creating critical problems for the country today.

In the survey results, "Minimizing Waste Disposal Issues" (ES4) received the second highest score, which is a deviation from the interview findings. However, the interviewees also stated that the current problematic situation in the country with regard to waste is mainly due to the excessive quantity of domestic waste generated in urban areas while the overall quantity of waste generated in the infrastructure sector is lower by comparison. However, they highlighted that within a project the waste issue should be given considerable attention, especially with regard to the quality and location of the waste that is disposed of. It supplemented the survey results where the issues related to "Ensuring Disposal in a Proper Location" (ES4c) received the highest score (7.2 %) under waste disposal issues. The difficulty of finding proper locations to dispose of waste is the main issue facing the country today. So Interviewee 1 stated that:

> *"The absence of proper locations to dispose waste is a severe issue in the country. This is not only for domestic waste but for all types of waste. Especially when disposing demolition waste in the construction industry, project teams should be careful to find suitable locations. Mostly these wastes are dumped into water bodies or into abandoned paddy fields or other bare lands creating pollution issues and disturbing neighbourhoods. Even the wastes collected by relevant authorities are disposed of in such locations sometimes. Therefore the location issue should receive more attention currently. In infrastructure projects, demolition waste and excavated materials can be used as filling materials but no proper arrangements are made in many projects. Therefore such practices should be addressed in ERSs to lessen the waste issue in the country."*

Although the quantity of waste disposed of from a single project could be low, the cumulative impact of waste disposal over a long period of time in the same locations can be adverse in terms of the environment. As Interviewee 3 pointed out:

> *"We know that the waste issue is a severe problem nowadays in the country. Construction wastes are not exempted, especially demolition waste. The reason is the absence of a proper location and mechanism to dispose of this demolition waste. It is the normal practice to dump them in some marshy lands and it happens then continuously over long periods of time. "Aththidiya" marshy land is an example that threatened many species due to demolition waste being dumped there over years. Even though the quantity from individual projects may be small, the cumulative impacts over time on these locations would be severe."*

Interviewee 1 highlighted the importance of segregating the different types of waste. According to him, increasing the quality of the waste disposed of by the projects has not been properly addressed in the country yet:

"The failure to sort out and treat waste properly is worsening the waste issue in Sri Lanka. In the construction projects, the project teams should be careful to sort out their waste before disposal and to take necessary actions for any hazardous wastes."

Waste cannot be eliminated. Hence, it is important to minimize the harm caused to the environment as much as possible. This is reflected in the survey results as well. Issues related to "Harmful quality of waste" (ES4b) received the second highest score (7.1 %) under "Waste Disposal" (ES4) issues. As Interviewee 6 put it:

"A certain quantity of waste cannot be eliminated in any project but the quality of that waste should be considered in the first place because if the quality of waste is not harmful, fewer problems will occur during disposal. Then the location problems also can be eliminated. For example, the "Kandalama Hotel" project attracted many protests due to its site which is closer to a lake and people believed that waste from the Hotel will be discharged into the lake and many environmental and health problems would occur. But, now, the hotel management has implemented a sophisticated waste water treatment methodology, hence no problems have occurred even though they discharge this treated water into the lake. The problems of waste quantity and location therefore have been eliminated by treating effluent."

8.4.5. Investment in Natural Capital (ES5)

Investment in natural capital is seen as important but with limited opportunities at the project level. The survey results showed that it is in the fifth position among the eight factors. In the interviews, this factor is mainly seen in terms of forestation. Interviewee 17 stated that:

"Investment in natural capital is important for environmental protection and to help biodiversity conservation where the forestation is a major part of that in the country."

However, the interviewees did not see the depletion of the vegetation cover as severe in Sri Lanka although in fact the forest cover depletion is quite considerable. They thought that due to the home garden concept and Sri Lankan lifestyles, the vegetation cover is not as much affected. Interviewees 11 and 16 had the following observations to make, respectively, on the subject:

> *"Although the forest cover is affected by development activities, the vegetation cover is not considerably depleted. This is because Sri Lankan home gardens typically comprise vegetation including large trees and other species. Therefore, vegetation cover in the country as a whole will not display a remarkable depletion. Another reason is the changing lifestyles and employment patterns from agriculture to industrial sectors. As a result of these changes, "Chena" cultivation has reduced and forest clearance in the hill country and some dry zone areas has been minimized".*

> *"Although the forest cover depletion is difficult to eliminate with the current developmental trend, vegetation cover is not severely depleted in the country due to the lifestyles of the general public who are interested in home gardens and small agricultural lands."*

Among the two sub-factors evaluated under "Investing in Natural Capital" (ES5), investing "To enhance the natural capital stock" (ES5b) (4.3%) was seen as carrying limited opportunities due to the shortage of land availability as mentioned earlier. Therefore, investing "To maintain the natural capital stock" (ES5a) (5.8%) was seen as more important than enhancing the natural capital, a position also reflected in the survey results. So Interviewee 6 stated that:

> *"Although it is very important to enhance the natural capital stock of any country, regarding forestation, there is a limit on land availability due to the growing developmental trend and increasing population. For example, under the current government vision, forest cover in the country is expected to increase up to 35% of the country's total land area but physical planners face the issue of land shortage in achieving such a target without*

neglecting human and social development needs. Hence, maintaining the existing natural capital stock is of immense importance even though the enhancement opportunities are limited."

Opportunities to enhance natural capital stock depend upon the type of infrastructure, with some types providing better opportunities to invest in natural capital and to enhance its stock as part of the project than others. Large reservoir projects are the best examples of this type found in Sri Lanka, the 'Mahaweli Development Program' being a case in point. Interviewee 15 highlighted the measures taken under this program in the following manner:

"Infrastructure projects can plan to compensate the loss of natural capital stocks and enhance the environment. For example, 'Mahaweli Development' cleared 200 hectares of lands in the dry zone but on the other hand, they invested in three national parks and sanctuaries. More examples can be seen in the hydropower and irrigation sectors. 'Lunugamwehera Reservation' was declared under the 'Weheragala' dam project and the 'Udawalawa Reservation' was declared under the 'Udawalawa' dam project creating large habitat areas for flora and fauna in the country."

Such measures directly benefited biodiversity conservation as well since they enhanced habitat areas. As Interviewee 8 said:

"The investment in new natural capital stocks like forestation is benefited for biodiversity conservation as well"

However, in order to get this benefit, consideration should be given to the types of species selected for plantation. This is important where awareness of invasive plants is increasing in the country. Thus, appropriate species should be planted to derive the maximum benefits and to avoid detrimental consequences. Interviewees 7 and 11 made the following statements, respectively, on the issue;

"Early plantations like Pines and Eucalyptus are blamed for losing water tightness in the central hill country and therefore the types of species should be selected carefully for forestations."

"Attention should be paid to which kind of species we are planting. We can see that there are forest plantations in the central hill country with inappropriate species and some are considered as invasive species today. Studies on native flora species are required today to identify the most appropriate species for re-plantation."

8.4.6. Biodiversity Conservation (ES6)

"Biodiversity Conservation" (ES6) was also identified as important in achieving environmental sustainability in the Sri Lankan infrastructure sector today by many of the interviewees. This is evident from the survey results as well where ES6 achieved the highest score (19.1%). This is really important with the current developmental trend that appears to be moving away from urban areas to cover the entire country, including the rural areas where most of the ecologically sensitive areas are located, which were less affected by development previously. Interviewee 7 pointed this out as seen in the excerpt given below:

"Biodiversity conservation is the most important factor that should be considered during this boom in infrastructure developmental activities which is moving away from urban areas and spreading all over the country".

Another reason for the perceived importance of biodiversity conservation is that once biodiversity is lost, man cannot re-create it with technology, which makes it imperative to conserve it while development is in progress. Interviewee 4 points this out in the extract below:

"Biodiversity is the most important aspect because there is no option if we lose the natural properties of our eco system. We cannot create these natural properties of the ecosystem with any known science or technology. Therefore, conserving biodiversity is of immense importance".

Although some factors like land use and materials use are necessities that cannot be eliminated in developmental activities, serious biodiversity losses must be avoided at all costs because such losses are irreversible and irrecoverable. As Interviewee 8 states:

> *"Biodiversity conservation is the most important factor. Other factors such as materials usage and land usage are difficult to control with developmental trends but, even during developmental booms, conserving biodiversity should be considered and it can contribute a lot to protect the natural environment."*

Loss and fragmentation of habitats are the major impacts of infrastructure projects that adversely affect biodiversity. Transportation networks and large reservoir projects are the major types of infrastructure that are most responsible for this issue. However, almost all types of infrastructure that are located in ecologically sensitive areas have some impact on habitat loss and fragmentation. As Interviewee 3 stated:

> *"Fragmentation of habitats due to many infrastructure projects adversely impacts biodiversity in the country. Not only major road construction projects but also other project types which require access roads and other facilities cause this fragmentation and affect habitats and species."*

Although not all the losses can be eliminated, as stated earlier, serious biodiversity losses can be eliminated through proper attention and planning strategies despite current developmental trends. Interviewee 3 cited an example of such action:

> *"Fragmentation and loss of habitats can be reduced through different strategies at the planning stage. For example, there was a project proposal for a new road construction into the northern part of the country which would have caused fragmentation of the 'Wilpatthu' forest reservation which is a significant and large habitat area in the country. However, the proposal was altered to expand an existing road to the area instead of the new road. Another example is the recent road project started in the 'Sinharaja' forest area which can cause irreversible damages to the*

heritage rainforest site due to fragmentation of the ecosystem and consequent losses of biodiversity. However, though the clearance works had already started, it has been suspended due to serious concerns expressed by many environmental groups."

8.4.7. Contributions to Eradicate Poverty (ES7)

"Contributions to Eradicate Poverty" (ES7) and "Avoid Corruption" (ES8) came last in order of importance in the survey results but both factors scored more than 7% of the total scores. The interviewees also suggested that although the policies strive to balance economic, social and environmental issues, these factors are barriers to the environmental sustainability of Sri Lankan infrastructure projects. Interviewees 2 and 5 made the following statements, respectively, on this issue:

"As a developing country and due to political issues, there is a trend for giving priority to economic and social issues at the expense of environmental damages"

"General practice is to be economical, socially desirable and environmentally friendly respectively. Being economical is the priority because we are a developing nation with lack of sufficient funds to realize infrastructure requirements.

With regard to ES7, the interviews revealed that, rather than poverty itself, public attitudes and political concerns driven by economic constraints are the major factors governing the lower priority given to environmental issues at the project level. However, the lack of funding is also a significant problem. Interviewees 1, 4 and 5 had the following to say, respectively, on this issue:

"For individual projects, the damages are not just due to poverty. The political system in the country pays more attention to socio-economic issues which result in the lower priority given to environmental issues due to trade-offs."

"Socio-economic issues are given priority even at the expense of damaging the environment due to political interests".

> *"Social issues have to be essentially considered to avoid public protests and to safeguard political interests. In such a situation, environmental issues receive the least attention due to tradeoffs between different aspects."*

Interviewee 9 supplemented this fact with an example from the road sector and stated that:

> *"Socio-economic issues receive the highest priority even at the expense of environmental damages. This is driven by the current political system as well. For example, to avoid public displeasure on the government party, roads are constructed through ecologically sensitive areas to minimize relocation. Another major reason for this is the cost of relocation. If the funding agency is not allocating funds for the cost of relocation, then it will be a burden to the government. Public also inflexible due to their attitudes towards relocation such as changing life styles, losing ancestors' properties, and so on."*

Interviewee 3 also confirmed this fact by stating that:

> *"It is true that priority is given to socio-economic issues rather than environment. For example, in road projects, alternative paths are evaluated to minimize resettlement in order to minimize cost of compensations. The result is choosing the path with minimum socio-economic impacts but which fragment biodiversity and encroach on ecologically sensitive areas. Likewise, a major reason for the damages to land composition is the selection of sites giving priority to social needs rather than environmental aspects."*

Hence, it is not just poverty but a combination of socio-economic issues that hinders the focus on environmental concerns in the country. Addressing such issues up to a certain extent would be beneficial in accomplishing the project with minimum public protests and minimum environmental damage. As Interviewees 16 and 17 put it:

“Addressing socio-economic issues at the project level is beneficial to minimize the burden to the government.”

“Indirect project level contributions for socio-economic issues are important.”

8.4.8. Avoid Corruption (ES8)

On the issue of “Avoid Corruption” (ES8) at the project level with regard to environmental matters, the interviews showed that although the country has proper environmental legislation, the problem is non-compliance due mainly to lack of monitoring and political support. Thus, Interviewees 15 and 5 stated that:

“The country’s legislation for environmental issues is satisfactory but there are issues in compliance and monitoring.”

“Non-compliance is severe at the project level.”

Interviewee 2 also highlighted the severity of non-compliance as well as the illegal use of environmental resources, indirectly, which occur during infrastructure development in remote areas. These severely affect the natural resources in the country.

“Illegal logging and sand mining by either project related parties or induced parties can be seen in many infrastructure projects in remote areas. In some road projects, a land area beyond the actual site has been cleared illegally for logging purposes”

Though there is a process under the Timber Corporation of Sri Lanka, according to Interviewee 18, for project-related logging, as Interviewee 2 said:

“Superseding these procedures and legislations can be seen in some projects”

8.5. Proposed Conceptual Framework

Section 6.5 presented the factors that are considered as important in achieving environmental sustainability in infrastructure projects and hence, should be considered in the conceptual framework for ERSs for assessing infrastructure projects in Sri Lanka and the hypothesis was presented in Section 6.6.

Based on the survey results and interview findings, it was identified that minimising impacts of land use under ES1, minimising impacts of usage of materials under ES2, minimising impacts of usage of non-renewable energy sources under ES3, minimising impacts of waste disposal under ES4, investing in natural capital to maintain and enhance its stocks denoted as ES5a and ES5b, conserving biodiversity denoted as ES6, and contributions to eradicate poverty denoted as ES7 are important into varied extents in achieving environmental sustainability in infrastructure projects in Sri Lanka and hence, appropriate to consider in infrastructure-related ERSs in Sri Lanka with appropriate weightings to reflect their relative importance.

In Sections 6.5.2 and 6.6 it was hypothesized that "Avoid Corruption" (ES8) is important in achieving environmental sustainability in Sri Lankan infrastructure projects. Interviews revealed that all the incidents of illegal activities and non-compliances are not due to corruption only. Lack of monitoring capacity in the public authorities and misbehaviour of the project team members are also causes for these activities in which no corruption activities are involved necessarily. This study aimed to propose a conceptual framework for ERSs for assessing infrastructure projects and hence, the focus lies on the performance of project and activities of project team. Therefore factor ES8 includes non-compliance with environmental laws and standards by the project team members where the reasons for this non-compliance can be corruption, lack of monitoring and also misbehaviour of project team. In the conceptual framework, the factor ES8 is named as "Compliance with Environmental Laws and Standards". An unpaired t-test was carried out on the responses of those who were interviewed (18 experts) and the responses of the rest of the group (33 experts) for each factor that showed slight deviations when stating the most important factor. The t-test showed that the differences can be considered to be not statistically significant.

Figure 8-2 presents the proposed Conceptual Framework for ERSs for assessing infrastructure projects in Sri Lanka in a hierarchical structure. It shows the importance/severity of factors affecting the environmental sustainability of infrastructure projects in Sri Lanka with regional priorities. The performance of projects towards achieving environmental sustainability can be assessed based on these criteria and weightings. Type-specific issues should be identified under each main factor or sub-factor at the lowest level to develop type-specific ERSs. Chapter 9 demonstrates the application of this framework to the SHP sector in Sri Lanka.

8.6. Validation of the Proposed Conceptual Framework for ERSs

Validation is a set of methods for judging the accuracy of the results of a study. It can be used to determine the applicability of the results in the particular context (Eddy et al., 2012). Peer or expert validation is widely used, where findings are shared with others who have expertise in the research phenomenon or the population (Lyons and Doueck, 2010). An expert review is a process asking the opinions, suggestions, feedback or comments from experts (Angkananon et al., 2013). The purpose of the validation in this study is to seek expert opinion on the proposed conceptual framework for ERSs for assessing infrastructure projects in Sri Lanka.

The validation exercise was conducted with experts who are engaged in environment- related activities in the Sri Lankan infrastructure sector. A group of experts, excluding those who were involved in the questionnaire survey and interviews, were asked to evaluate several factors that were to be included in the conceptual framework.

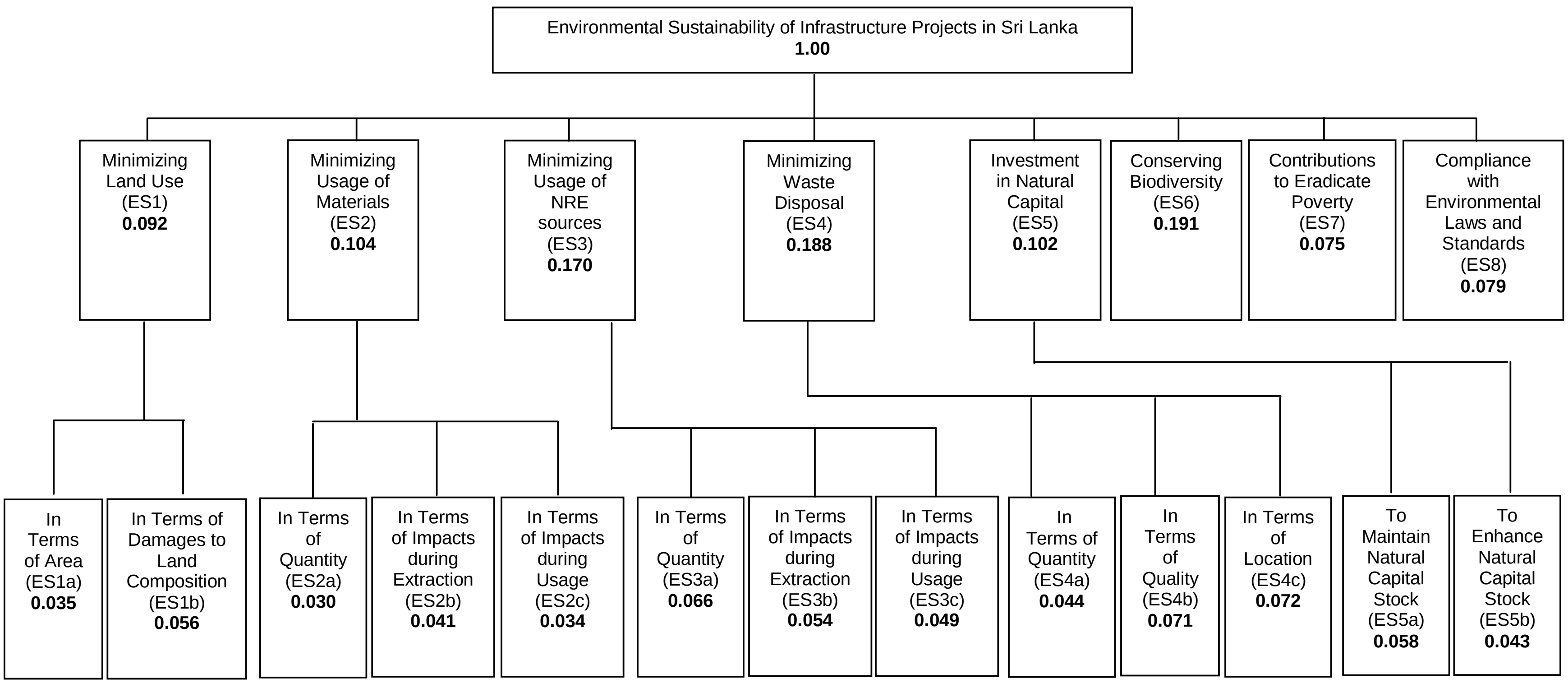

Figure 8- 2: Conceptual Framework for ERSs for Assessing Performance of Infrastructure Projects

Due to the time constraints, the proposed conceptual framework was sent to the group of experts through email. In the selection of validation participants, the key requirement was that they have experience and knowledge on environmental issues in the Sri Lankan infrastructure projects. In addition, they should have an understanding of the basic components and requirements of ERSs for environmental assessment of projects. The conceptual framework was sent to seven experts engaged in environment-related activities in the infrastructure and development sectors in Sri Lanka. Their profiles are given in Table 8-9. While the expertise of participants is essential for expert validation, there is no specified number of participants for the validation although the number in general is no more than ten (O'Keefe et al., 1987; Bryman and Bell, 2003).

Table 8- 9: Validation of the Conceptual Framework: Profiles of Experts

No.	**Designation and Role in the Sector**	**Experience in the Field (years)**
1	Environmental Consultant - Development Administration	25
2	Environmental Consultant - Development Administration	20
3	Environmental Manager and Consultant in Development Administration	20
4	Environmental Manager in Development Administration	10
5	Green Consultant, Expert in Environmental Assessment and Academic Professional	5
6	Expert in Environmental Assessment	5
7	Academic Professional – Environmental Management	5

8.7. Discussion on Validation of Results

The proposed conceptual framework mainly consists of factors determining the environmental sustainability of Sri Lankan infrastructure projects and their relative importance. These factors should be considered in assessing the performance of projects with regard to environmental sustainability, which forms the basis for criteria selection. The weightings provide the basis for point allocation to the criteria. Chapter 3 explained that ERSs offer comprehensive assessment systems that cover a range of factors with the recommended practice being life cycle coverage. Therefore, the experts were asked to comment on the comprehensiveness, the life-cycle coverage, and the relevance of the factors included, the weightings indicating the relative importance of each factor. Experts were asked to rate the level of agreement on the relevance of each factor on a scale of 1 to 5 from “Strongly Disagree” to “Strongly Agree. They were also asked to rate the level of comprehensiveness and life-cycle coverage of the conceptual framework on a scale of 1 to 5 from “Not Satisfactory At All” to “Very Satisfactory”.

The ratings given to the relevance of factors ranged between 3.71 and 5.00 in terms of level of agreement as shown in Table 8-10. The ratings for six ES factors, namely, Land Use (ES1), Usage of Materials (ES2), Usage of Non-renewable Energy Sources (ES3), Waste Disposal (ES4), Investment in Natural Capital (ES5) and Biodiversity Conservation (ES6), showed strong agreement regarding their relevance. The level of agreement on the factor “Complying with Environmental Laws and Standards (ES8)” ranged from “Agree” to “Strongly Agree” which came to 4.14. The level of agreement on the factor “Contributions to Eradicate Poverty (ES7)” ranged from “Neutral” to “Agree” but was closer to the “Agreed” level at 3.71.

Table 8- 10: Results of Expert Validation

ES Factor	Relevance
ES1 – Land Use	5.00
ES2 – Usage of Materials	5.00
ES3 - Usage of Non-renewable Energy Sources	5.00
ES4 – Waste Disposal	5.00
ES5 – Investment in Natural Capital	5.00
ES6 – Biodiversity Conservation	5.00

ES7 – Contribution to Eradicating Poverty	3.71
ES8 – Compliance with Environmental Laws and Standards	4.14

- Land Use (ES1)

  Experts are strongly agreed on the inclusion of issues related to land use in infrastructure-related ERSs. In their view, this is important for infrastructure projects which use large tracts of land compared to buildings. They also agreed that addressing damages to land composition is important because most of the land use problems were due to damages caused to the ecological value of sites.

- Usage of Materials (ES2) and Non-renewable Energy Sources (ES3)

  Experts were strongly agreed on the relevance of issues related to usage of materials and non-renewable energy sources in infrastructure-related ERSs. They also felt that it was important to address sub-factors on the types of materials used and sources of extraction in addition to the issue of minimizing the quantity of usage. This is because there is more awareness now regarding the health and environmental costs due to use of hazardous materials as well as on the importance of addressing sources of extraction which can eliminate damages due to unsustainable extraction. In the opinion of the experts, though it is not always possible for project teams to know the sources of extraction, ERSs can raise awareness on environmentally unsustainable extraction practices and encourage environmentally sustainable extraction practices up to a certain extent.

- Waste Disposal (ES4)

  Experts were strongly agreed on the relevance of issues related to waste disposal in infrastructure-related ERSs. Addressing sub-factors on the quality of waste disposal as well as the location of such disposal are important in raising awareness on and encouraging proper waste management practices through ERSs.

- <u>Investment in Natural Capital (ES5)</u>

  In the view of experts, though investment in natural capital is important for environmental sustainability, project-level contributions to such investment are not very common. However, experts agreed that including such factors in ERSs would encourage such practices.

- <u>Contributions to Eradicate Poverty (ES7)</u>

  In the view of experts, though addressing socio-economic issues for the purpose of eradicating poverty is indirectly helpful towards ensuring environmental sustainability in the Sri Lankan infrastructure sector, not all project types would be able to implement such practices due to small scale or the type of the project.

- <u>Compliance with Environmental Laws and Standards (ES8)</u>

  In the opinion of experts, addressing compliance with environmental laws and standards at the project level is important in order to ensure the environmental sustainability of development projects in Sri Lanka. However, issues regarding evaluation can be raised when ERSs address them. Therefore, in the view of experts, it would be more appropriate to make these issues prerequisites in ERSs while requiring project proponents to submit endorsements from the relevant authorities to support their claims of environmental sustainability.

In sum, experts are strongly agreed on the factors, ES1 - ES6, which address direct ecological issues though they pointed out that ES5 is not commonly implemented in ERSs. Moreover, though they pointed out the difficulties inherent in evaluating factors ES7 and ES8, they agreed that these factors can pose a barrier to the environmental sustainability of the projects and that, if evaluated and implemented properly in ERSs, they would enhance the environmental sustainability of the said projects. One of the interviewees whose expertise lies in environmental assessment, and who is involved in developing ERSs, stated that they have considered assessing project performance, in future versions, in terms of its contribution to society as a whole, which would be similar to the factor of socio-economic contributions mentioned in the proposed conceptual framework. However, he also stated that although they have discussed corruption issues as well, they have not arrived at a final decision on whether to include such criteria because of problems when it comes to evaluation. Although the present study did not include the measurement/evaluation phase of ERSs in its scope, the experts suggested as one way to measure such issues the mode of public complaints, which usually happens in the case of Sri Lanka. OECD (2009) too showed that public complaints can be used to evaluate the environmental compliance of entities.

When the conceptual framework and the factors identified were presented to the experts, they found the implementation framework to be generally acceptable. They also found the comprehensiveness and life-cycle coverage of the conceptual framework in addressing environmental issues of Sri Lankan infrastructure projects to be between the “satisfactory” and “very satisfactory” levels. Although they found the evaluation of some factors to be difficult, if measures to evaluate them are explored and implemented properly in ERSs, the ERSs can raise awareness of and encourage adoption of environmentally sustainable practices in the infrastructure sector more than is the case with the sector now.

With regard to the weightings, the experts on the whole commented that the assigned weightings are generally appropriate to reflect the current needs of the Sri Lankan infrastructure projects. Furthermore, they pointed out that with the changing nature of developmental activities and the associated environmental issues, the relative importance of issues may change over time. Therefore, the method adopted in the present study of breaking down the problems into several levels in addressing the issues is useful because it enables the modifications of the weightings according to the relative importance of factors at any given point in time.

8.8. Summary

The chapter presented the analysis of survey data and the results with regard to the significance of major factors in the proposed conceptual framework. The conceptual framework comprises two hierarchical levels: the main factors as well as sub-factors under some of the main factors. The relative importance of each factor was calculated using the AHP technique. The chapter also presented the interview findings which supplemented the survey results on the importance of factors for assessing the environmental sustainability of Sri Lankan infrastructure projects. It also presented expert validation of the proposed conceptual framework for developing infrastructure-related ERSs in Sri Lanka.

Chapter 9: Application of the Conceptual Framework to the SHP Sector in Sri Lanka

9.1. Introduction

The chapter demonstrates the application of the conceptual framework for ERSs for assessing Sri Lankan infrastructure projects to the SHP sector. It also explains the field survey and the interviews carried out with both the public in the vicinities of SHP projects as well as experts in the sector in order to elicit the specific environmental issues of SHP projects. The chapter then presents the analysis of the survey data using the AHP technique. It measured the relative importance of each factor, the main findings of which are highlighted in this chapter. The chapter also presents the interview findings together with the survey results. The interviews were carried out with the experts in the Sri Lankan SHP sector in order to supplement the survey results.

9.2. Field Visits, Interviews and Other Observations on Impacts of SHP Projects

Data collection on environmental issues specific to the SHP sector began by referring to EIA reports and IEE reports of SHP projects. Although more than 100 projects have been implemented, it was noted that due to the small scale, many projects have not been subjected to the EIA or IEE process. The three reports that were found in the Central Environmental Authority (CEA) library were therefore referred and the impacts identified in them were listed. As evident from Table 9-1 and Figure 9-1, all the reports highlighted similar issues.

To explore more issues relating to SHP projects, a field survey was carried out. A majority of the SHP projects is located in the hilly forest areas of the Central and Sabaragamuwa provinces. A few projects are located in the dry plains which are operated under irrigation canals and river stretches. Some of these areas such as Rathnapura, Ginigathhena and Nawalapitiya areas in the

Central and Sabaragamuwa provinces were visited in order to solicit the opinions of the general public living in the vicinities of the SHP projects. In addition, the Maduruoya area (Eastern Province plains) was visited which represents SHP projects located in the Dry Zone plains.

The respondents were selected with care for the purpose of eliciting reliable data on the environmental impacts of SHP projects. Therefore, mostly, school principals, teachers and village-level officials were interviewed as representatives of the general public. While some of them were members of the village communities under consideration, others though outsiders, had spent long years in the locale. Open-ended questions were directed at these respondents on their experiences and ideas as well as public perception in their villages regarding the impacts of SHP projects in the area. The sample size was determined by the point of redundancy of the list of issues identified. Interviews were therefore conducted until the list of issues reached a point of redundancy where no novel issues were being added to the list. As Table 9-1 and Figure 9-1 show, after Respondent 11, the number of issues identified has not increased. It was thus considered as the data redundancy point to finalize the list of issues. In Table 9-3, these issues are listed under each project phase according to either the frequency of appearance in the sources or as stated by respondents in Table 9-1.

Table 9-1: Data Redundancy Point

Source	**No. of Problems**	**No. of Positive Impacts**	**Total No. of Impacts**
EIA/IEE report 1	5	0	5
EIA/IEE report 2	16	1	17
EIA/IEE report 3	16	1	17
News article 1	16	1	17
Respondent 1	17	1	18
Respondent 2	18	1	19
Respondent 3	18	1	19
Respondent 4	18	2	20
Respondent 5	19	2	21
Respondent 6	20	2	22
Respondent 7	20	2	22

Respondent 8	21	3	24
Respondent 9	21	3	24
Respondent 10	21	3	24
Respondent 11	23	4	27
Respondent 12	23	4	27
Respondent 13	23	4	27
Respondent 14	23	4	27

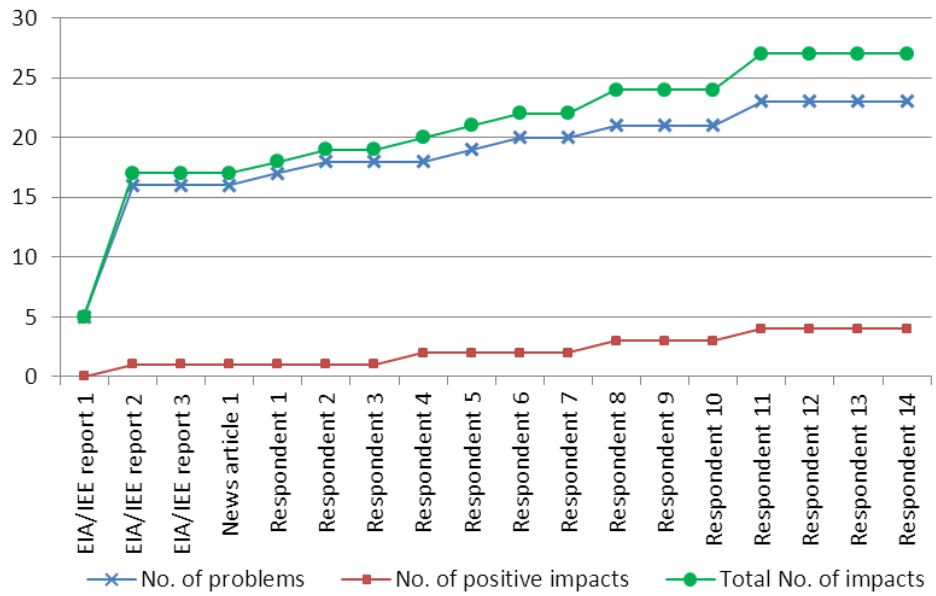

Figure 9-1: Data Redundancy Point

9.3. Environmental Issues Identified in Sri Lankan SHP Projects

As shown in Table 9-1, a total of 27 issues relating to SHP projects were identified through the field survey. Of these, 23 can be classified as environmental problems and 4 classified as positive impacts. Table 9-3 lists these issues and shows the frequency with which these issues were identified in different sources in the field survey. This section briefly explains each of the issues identified under each stage of the project life cycle.

9.3.1. During Site Selection and Construction

(1) Inundation of valuable forest areas

As shown in Figure 5-3, in SHP projects, water is diverted from a river or stream at the intake. As explained in Section 5.4.1, typical SHP projects comprise a water diversion circuit including the headrace channel (an open channel or tunnel) that transmits water into the power station. Typically, these projects comprise a diversion structure such as a small dam or a weir at the intake. Another type of SHP project includes water storage structures including a storage pond. However, the extent of the submerging area is small compared to large-scale hydropower projects. Depending on the project and location, the area of submergence or flooding due to diversion or storage structures can be different.

(2) Clearance of valuable forest areas for permanent and temporary works

As shown in Figure 5-3, and as explained in Section 5.4.1, SHP projects comprise several permanent structures such as channels or tunnels, a fore-bay tank and power station. They also require temporary facilities such as access roads to transport materials and construction equipment, temporary storage facilities for materials and equipment, and workers' huts. Since SHP projects are based on a water body, most of them are located in ecologically sensitive as well as rural areas with no adequate facilities such as access roads. Depending on the location, most SHP projects cannot avoid clearance of vegetation and, sometimes, forest areas for permanent and temporary works.

(3) Clearing an area that is more than the actual land requirement, thus disturbing it for project activities, and then abandoning it

As stated under the previous impact, vegetation and forest areas are cleared for temporary work. If not planned carefully, these temporary facilities may still disturb the environment even though they may be abandoned after the construction phase of the project.

(4) Felling large trees for the construction of project components

As stated earlier, the locations of projects are in ecologically sensitive areas. Hence, channel paths and transmission lines are mostly laid through forest areas, which require clearing vegetation and, sometimes, felling large trees.

(5) Soil erosion risk during construction

As stated earlier, SHP projects are based on a water body. And the soil erosion risk is higher in such areas that are close to river banks. This risk is increased due to vegetation clearance, felling of trees and construction activities.

(6) Damage to the area due to rock blasting

Many locations with water bodies comprise rocks or boulders. Thus, rock blasting may be required to place diversion structures as well as for the purpose of locating the power station.

(7) Damage to the area due to excavation

As stated earlier, channel/tunnel paths mostly lie through forest areas. Thus, excavation work, for these purposes, damages the vegetation cover and ecological balance of these areas for a considerable distance depending on the project.

(8) Loss of aquatic species due to blasting activities

As stated earlier, rock blasting is required to construct diversion structures and it affects aquatic species. The field survey revealed that there had been occasions when rock blasting in SHP projects caused the death of nearly extinct fish species in the central hill areas.

(9) Dumping of excavated materials causes soil erosion and consequent siltation

Since the project locations are close to river banks and hilly areas, if appropriate methods are not adopted for proper stock-piling and for disposal with the necessary precautions, excavated materials can be finally deposited in the water body due to rain water flows causing siltation consequently.

(10) Disposal of waste generated during construction into surrounding areas

If proper methods are not adopted to carefully dispose of excavated materials and other construction waste such as materials packaging, workers' waste foods, and so on, such waste would inevitably disturb the surrounding areas.

(11) Impacts to water quality during construction

Since SHP projects are based on water bodies, there is a risk to water quality during construction activities due to construction waste.

(12) Loss of aquatic and terrestrial species (both flora and fauna)

Due to clearing of vegetation and felling of trees, terrestrial flora species can be lost. SHP projects may also impact on terrestrial fauna species due to habitat losses. During construction, aquatic flora and fauna species can be affected due to rock blasting and other construction activities.

9.3.2. During Construction and Operation

(13) Illegal logging

The field survey revealed that, illegal logging can take place, especially during construction, due to the migration of construction workers to the locality.

(14) Animal poaching

The field survey also revealed that poaching can happen during construction due to the migration of a construction workforce to the locality. This could continue during the operational phase as well.

(15) Spread of invasive species in the disturbed area during construction

The IEE reports showed that there is a risk of spreading invasive species in SHP project areas. Construction sites are at high risk of spreading invasive species (NCHRP, 2006) after the construction phase due to foreign substances contained in materials and other stuff brought to the site. These are species that establish them in the wild beyond their natural distribution range following the intentional or accidental transportation of either whole plants or propagules by humans or human-related activities, which are harmful to the biodiversity of a particular area (Arroyo et al., 2000). Since SHP projects are generally located in ecologically sensitive, and biodiversity rich, areas, the risk is higher. The field survey revealed that programs are undertaken in some areas to remove these species where they spread over a larger area. Identification of invasive species, however, takes time. But it should not be neglected because these projects are based on water bodies, which can be a mode of transmitting weeds, thus increasing even more the risk of spreading some invasive species.

(16) Impact on the biodiversity of aquatic species and terrestrial species along and close to the river bank due to dry conditions of the affected river stretch

The risk of dryness between the water intake and the tailrace discharge due to water diversion is one of the issues most noted during the field survey. This can exacerbate during the dry season when the natural water flow is anyway low, and during which period the project team may block the natural water flow to increase the diverted water flow. However, there is a recommended environmental flow that should be released and maintained continuously as prescribed for each SHP project by the project approving authority. The project team should comply with this environmental standard.

(17) Impacts on animal safety due to large open channels with high-speed water flow

As explained in Section 5.4.1, water can be transmitted from intake to powerhouse using channels or tunnels. In case of channels, they are generally open channels with a considerable flow of water. When SHP projects are located in habitat areas of animals, there is a risk of animals falling into these channels. The field survey found reported instances of such accidents. Due to the speed of the water flow and the height or steepness of slope of the channels, animals may not able to come out safely were they to fall in. According to experts, concrete slabs should be laid at intervals to pre-empt such tragedies, an aspect that should be considered under avoiding loss of species during construction and operation.

(18) Accumulation of sand, mud and waste

Although not as extensive as in large-scale dam projects, sand, mud and waste accumulation in the inundation pond (if any) or near the weir and intake can result in siltation, GHG emissions due to anaerobic decaying, or harm to aquatic species.

(19) Less water due to unsuitable plantations in the upper catchment

It was also noted during the field survey that the central hill country is facing a serious problem due to loss of water retention ability, which is believed to be mainly due to inappropriate plantations in the catchment areas.

(20) Quality of tailrace water discharge into the stream after use

Several interviewees mentioned during the field surrey that they were suspicious of the quality of the water discharged at the tailrace, which may then have a harmful impact on both aquatic species as well as the quality of the water available.

(21) Impacts on water quality during operations due to emergency situations

There is a possibility of oil leakage during emergency situations such as accidents or transformer breakdowns, with the risk of leaked oil becoming mixed with the water body. Though such situations have not been reported yet, there will be adverse impacts on both water quality and aquatic species in such an eventuality if necessary preventive measures are not considered.

(22) Drying out of springs due to the extreme dryness caused by the cumulative impacts of multiple SHP projects in the same area

Several interviewees during the field survey communicated a shared perception among residents of areas with multiple SHP projects that the drying out of natural springs in their respective locales was due to the cumulative impact of multiple SHP projects in the same area. This can be due to construction activities such as rock blasting, clearing of vegetation and dryness in the affected river stretches.

(23) Cumulative impacts on biodiversity along and near the river bank due to dry conditions

As was the case with issue (22), several interviewees noted during the field survey that, in areas with multiple SHP projects, some tree species are dying. Residents in the locality attribute it to the dryness of affected river stretches resulting from locating several SHP projects in the same area.

(24) Employment opportunities for locals

The construction stage offers a considerable number of employment opportunities for local people. Though the number is less, a few opportunities are available during the operational stage as well.

(25) Declaration of Forest reservation area

In general, some areas in the upper catchment of SHP projects are declared as a forest reservation, making those areas out of bounds for human activities such as logging, clearing vegetation and so on.

(26) Developing local facilities as part of the project for continuous use after construction of project

A majority of SHP projects is located in rural areas that suffer from a dearth of infrastructure facilities such as roads and electricity. Thus, access roads and electricity transmission lines set up for the use of the SHP projects can be improved further for the continuous usage of residents of the locality even after the construction stage. This not only indirectly benefits residents of the locality but creates goodwill between the project team and the local community in situations where environmentally sensitive projects mostly face protests from the general public of the respective vicinities.

(27) Social welfare projects for community carried out by SHP project owners

As stated earlier, a majority of SHP projects is located in rural areas which suffer from lack of facilities as well as being home to low income groups. The field survey revealed that SHP project developers carry out various community services, either initiating or assisting with social welfare programs of the villages. These activities help secure the good will of the local people for the project as well.

9.4. Validation of environmental issues identified in SHP projects

In order to validate the list of impacts identified and to find possible solutions for the problems identified, interviews were carried out with a group of experts involved in the SHP sector. Several rounds of discussions were carried out with this group until the list of impacts and the possible solutions were finalized. Table 9-2 shows the designation and role of each expert in the SHP sector. The selection of this group of experts was explained in Section 7.6.

Table 9-2: Interviews with Experts in SHP Sector – Profiles of Experts

Interviewee	Designation	Role in the SHP Sector
1	Professor in Zoology	EIA expert (preparing, evaluating and monitoring EIAs)
2	Professor in Forestry and Environmental Science	EIA expert (preparing, evaluating and monitoring EIAs)
3	Environmental Officer	EIA expert (evaluating and monitoring EIAs)
4	Geologist	EIA expert (preparing, evaluating and monitoring EIAs)
5	Hydrologist	EIA expert (preparing, evaluating and monitoring EIAs)
6	Environmental Manager	Working in a SHP development company
7	Environmental Manager	Working in a SHP development company
8	Hydropower Engineer	Managing SHP projects
9	Hydropower Engineer	Managing SHP projects
10	Hydropower Engineer	Environmental assessment and monitoring
11	Officer in Non-government Organization	Environmental assessment and monitoring

According to the experts, "Quality of tailrace water discharge into the stream after use" (Table 9-3) is not a problem in the SHP sector today because of the closed loop systems that retain the flow of oil matter inside the machinery, which prevents any negative impact on water quality. The study therefore did not consider that impact for further analysis.

With regard to cumulative impacts, the experts stated that a master-plan for SHP project locations is not available as yet and that relevant authorities should take the necessary measures to mitigate such impacts during approval of project locations since these issues are beyond the control of project developers. Hence, the experts did not recommend the inclusion of such issues in the ERSs. Therefore, cumulative impacts such as drying out of springs and drying out of flora species along the river banks (Table 9-3) due to the location of multiple SHP projects in the same area were not considered for further analysis in the study.

With regard to the issue of "Declaration of a forest reservation area" (Table 9-3) based on SHP projects, it was determined that while that would be beneficial for the natural environment, it is something that comes within the purview of the country's legislation and not necessarily to be considered as a matter of the project's individual performance. The experts therefore suggested that it should not be considered in ERSs. However, if the project team is cultivating plantations in the surrounding area, such efforts should be considered in ERSs.

The list of impacts and possible solutions identified for further analysis are illustrated in Table 9-3. The environmental problems were listed under different stages of the project such as site selection, construction and operation. The positive impacts were listed separately. The group of experts were asked to fill a chart, as shown in Appendix-2, to establish the relationships between the impacts of SHP projects and the ES factors in the conceptual framework as presented in Figure 8-2. The group of experts were asked to tick the chart for all the impacts under the relevant ES factors.

Table 9-3 gives the relevant ES factor for each impact identified. The subsequent hierarchical levels were formed based on these results. The hierarchical structures under each ES factor are explained in Section 9.5 while

Figure 9-14 illustrates the complete hierarchical structure. A questionnaire (Appendix-3) was prepared based on this hierarchical structure. Several rounds of discussions were carried out using the chart and re-checked the responses with the experts in order to avoid unnecessary items in the questionnaire which would only make it lengthy. The group of experts was asked to perform the pair-wise comparison of factors specific to SHP projects during the interviews. They were asked to fill the questionnaire during face-to-face interviews in order to discuss the reasons for their responses. The responses were then analysed using the AHP technique. The results of the analysis are demonstrated hereafter together with the interview findings in order to supplement the survey results.

Table 9-3: Environmental Issues of SHP projects, Possible Solutions and Related ES Factors (as per Appendix-2)

Issues Identified		Frequency	Possible Solutions	Related ES Factor
During Site Selection and Construction				
1	Inundation of valuable forest areas	1	Minimizing submerged areas	ES1a
2	Clearance of valuable forest areas for permanent and temporary works	7	Avoiding selection of ecologically valuable sites where possible	ES1b
			Minimizing land take for - Temporary works - Permanent works	ES1a
3	Clearing an area that is more than the actual land requirement, thus disturbing it for project activities, and then abandoning it	2	Minimizing the area used for temporary facilities through - Incorporating temporary facilities into permanent works - Improving local facilities as part of the project	ES1a
4	Felling large trees for the construction of project components	8	Minimizing the felling of trees Compensating by replanting lost tree species	ES6
5	Soil erosion risk during construction	4	Taking preventive measures to avoid soil erosion during construction	ES1b
6	Damage to the area due to rock blasting	3	Minimizing rock blasting activities and including preventive	ES1b

			measures to reduce damages	
7	Damage to the area due to excavation	1	Minimizing excavation and adopting preventive measures to reduce damages	ES1b
8	Loss of aquatic species due to blasting activities	3	Avoiding loss of aquatic fauna species	ES6
			Compensating for species if losses are unavoidable	
9	Dumping of excavated materials cause soil erosion and consequent siltation	5	Avoiding the disposal into river	ES4c
			Avoiding the disposal into nearby lands	
10	Disposal of waste generated during construction into surrounding areas	1	Avoiding disposing waste into nearby lands	ES4c
11	Impacts to water quality during construction	1	Minimizing waste disposal	ES4a
			Avoiding waste disposal into the river	ES4c
12	Loss of aquatic and terrestrial species (both flora and fauna)	1	Preserving affected species where possible	ES5b, ES6
During Construction and Operation				
13	Illegal logging	1	Preventing illegal logging	ES8
14	Animal poaching	1	Preventing animal poaching	ES8
15	Spread of invasive species in the disturbed area during construction	1	Taking preventive measures to avoid invasive species after construction	ES5a, ES6

During Operation				
16	Impact on the biodiversity of aquatic species and terrestrial species along and close to the river bank due to dry conditions of the affected river stretch	12	Complying with environmental flow requirement	ES8
17	Impacts on animal safety due to large open channels with high-speed water flow	2	Preventing loss of animals due to open channels	ES6
18	Accumulation of sand, mud and waste	2	Clearing away sand, mud and waste periodically	ES5a
19	Less water due to unsuitable plantations in the upper catchment	4	Tree plantation in the surrounding areas with appropriate species	ES5b ES6
20	Quality of tailrace water discharge into the stream after use	3	Field survey revealed that SHPs were using closed systems of oily liquid flows inside the machinery and therefore there was no impact on water quality	
21	Impacts on water quality during operation due to emergency situations	1	Taking preventive measures to reduce oil leakages during emergency breakdowns	ES4c
22	Drying out of springs due to extreme dryness caused by cumulative impacts of multiple SHP projects in the same area	3	Taking into consideration the cumulative impacts, the availability of other SHPs nearby should be considered which requires a master plan for SHPs regulated by the relevant government authority which is beyond the control of the project developer	
23	Cumulative impacts on biodiversity along and near the river bank due to dry conditions	4		
Positive Impacts				
24	Employment opportunities for locals	6		ES7

25	Declaration of forest reservation area	4	Not considered as part of project performance	
26	Developing local facilities as part of the project for continuous use after construction of project	5		ES7
27	Social welfare projects for community carried out by SHP project owners	4		ES7

9.5. Hierarchies and AHP Calculations - Factors Assessing SHP Projects in Sri Lanka

9.5.1. Minimizing Land Use in terms of Area (ES1a)

The locations of SHP projects are determined by a water body. Hence, most of them are located in ecologically sensitive areas either in the central hills or in the dry plains of Sri Lanka. With the growing demand for SHP projects in Sri Lanka, it is important therefore to consider the possibility of minimizing the land take in these areas. As the field survey reveals (Table 9-3), the issues related to land area in SHP projects arise mainly from two types of land use:

1. Use of land for submerging area (if any);
2. Use of land for other project components such as:
    - Temporary works (such as workers' huts, access roads, and materials and plant yards)
    - Permanent works (power house, penstocks and channels).

Possible solutions to these issues relating to land use were discussed with the experts. The submerged area and the land area used for permanent works should be minimized through design and planning. To reduce the land take for temporary works, existing facilities in the locality can be developed and used where possible or temporary facilities can be converted eventually to permanent usage. These solutions under ES1a are presented in Figure 9-2 in a hierarchical structure. Table 9-4 gives the AHP results.

The increase in the use of land for SHP projects exacerbates the clearance of forest and vegetation cover. Minimizing the area used for other project components (0.578) received higher priority than that used for submerging area (0.422). This can be attributed to the fact that, although a few of the early SHP projects with inundation ponds faced problems with regard to submerging area, most of the current SHP projects in Sri Lanka have been developed with the run-of-river system.

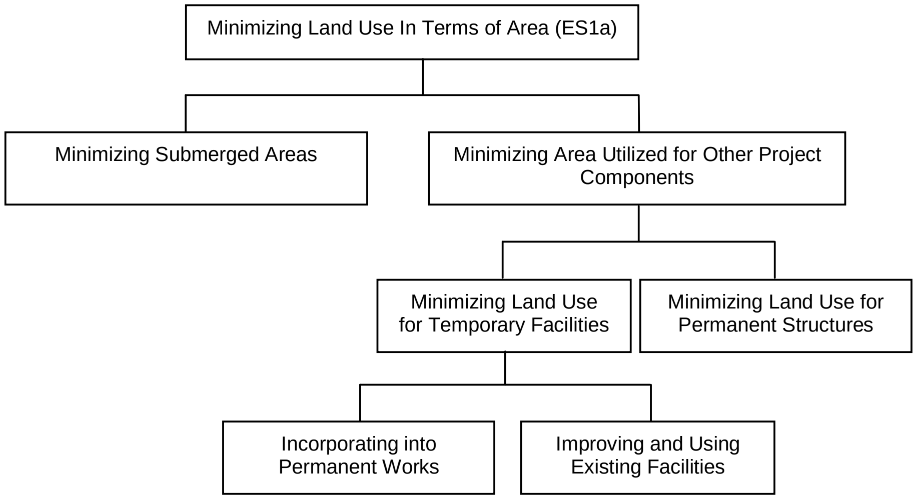

Figure 9-2: Land Use (ES1) Issues of SHP projects

However, the issue is not negligible if inundation were to take place. Hence, the issue should be considered in assessing SHP projects. As Interviewee 2 stated:

> *"If there is a submerging area, reducing this area is important because it is converting a terrestrial ecosystem into an aquatic ecosystem and is a permanent change."*

The field visit showed that in an old SHP project with a capacity of 3MW, several acres of forest areas had been affected. Both the location of most SHP projects in ecologically sensitive zones and the current growth in SHP development in the country, it is important to follow the run-of-river system and to minimize inundation of ecologically valuable forest areas.

Minimizing land use for permanent works (0.73) received higher priority compared to temporary land use (0.27). As Interviewee 2 stated:

> *"Vegetation cover in temporarily cleared areas will grow after a few years but permanent land use is irreversible and hence should be minimized."*

Table 9-4: Weightings of Land Use Issues (in terms of area – ES1a) in SHP projects

	Submerged Areas	Area for Other Components	Normalized Weight
Submerged Areas	**1.00**	0.73	**0.422**
Area for Other Components	1.37	**1.00**	**0.578**
			1.000

	Temporary Use	Permanent Use	Normalized Weight
Temporary Use	**1.00**	0.38	0.27
Permanent Use	2.66	**1.00**	0.73
			1.00

	Incorporating into Permanent Works	Improving Existing Facilities	Normalized Weight
Incorporating into Permanent Works	**1.00**	0.83	**0.45**
Improving Existing Facilities	1.21	**1.00**	**0.55**
			1.00

However, temporary land use cannot be ignored because, if not carefully planned, valuable forest cover can be affected by temporary works as well which are not directly usable in the project thereafter. Among different strategies that can be deployed to reduce temporary land take, improving existing local facilities as part of the project (0.55) received higher priority than incorporating temporary facilities into permanent works (0.45). Since most of the SHP projects are located in forest areas where the access roads and other facilities are not available or not in good condition, project developers have to clear the forest area to access the site. As Interviewee 4 put it:

> *"Rather than clearing for new access roads, it is beneficial to improve the existing facilities for both the project's use and for the wellbeing of local people. In situations where no facilities are available, rather than abandoning these access roads, it is wise to improve them and incorporate into permanent use.*

9.5.2. Minimizing Damages to Land Composition (ES1b)

As stated earlier, SHP projects are located in ecologically sensitive areas and, with the growing demand for SHP projects, these areas can be heavily affected. In the field survey, it was revealed that some SHP projects are located in already disturbed sites, which means that these lands had been disturbed due to human activities during the colonial period, or thereafter, for rubber or tea plantations or for other home garden type activities. In other words, these are not virgin sites. Selecting such sites reduces the damage to land composition. However, some projects, according to reports, are located in virgin sites. Since SHP locations are determined based on the water head, virgin sites are not always excluded. In such instances, it is imperative to minimize damage to land composition.

According to the experts, in order to minimize damages to land composition, either ecologically valuable sites should be avoided where possible or, if that is not possible, damages should be kept to a bare minimum. Three such damages were identified in the field survey where it is necessary for preventive measures to be introduced depending on the site conditions:

- Soil erosion risk in the river banks due to the clearing of vegetation;
- Damage to the area due to rock blasting;
- Damage to the area due to excavation and dumping soil.

These issues are presented in the form of a hierarchical structure in Figure 9-3. The AHP results are shown in Table 9-5.

"Minimising damages to the selected land" (0.53) received slightly higher scores than "Avoiding selection ecologically valuable sites" (0.47). While the latter is not practical in many projects, the former is important in all the projects. As Interviewee 3 put it:

> *"Site selection of SHP projects is highly dependent on the water head and many potential sites are in ecologically sensitive areas and hence it is difficult to avoid damages."*

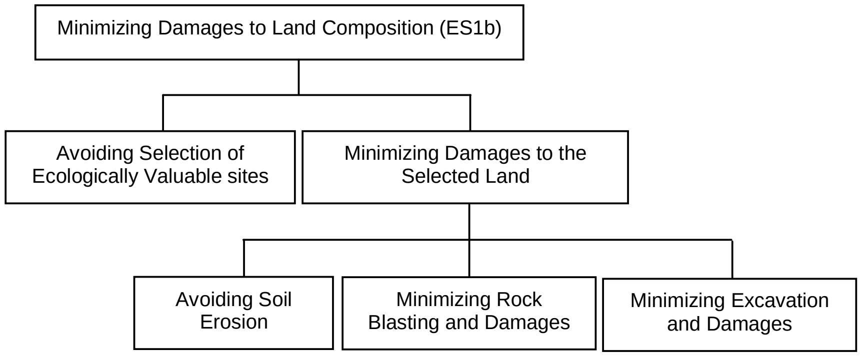

Figure 9-3: Land Use Issues (in terms of damages – ES1b) in SHP projects

SHP projects sometimes require rock blasting. Moreover, soil erosion is highly likely due to the clearance of vegetation cover near river banks. Additionally, excavating for channels and dumping excavated materials also damage the land composition.

Table 9-5: Weightings of Land Use Issues (in terms of damages – ES1b) in SHP projects

	Avoiding Ecologically Valuable Sites	Minimizing Damages	Normalized Weight
Avoiding Ecologically Valuable Sites	**1.00**	0.89	**0.47**
Minimizing Damages	1.13	**1.00**	**0.53**
			1.00

	Soil Erosion	Rock Blasting	Excavation	Normalized Weight	λ max
Soil Erosion	**1.00**	1.45	0.69	**0.31**	3.00
Rock Blasting	0.69	**1.00**	0.40	**0.20**	3.00
Excavation	1.44	2.50	**1.00**	**0.48**	3.00
				1.00	3.00

According to the results, minimizing ‘soil erosion’ (0.31) and ‘minimizing rock blasting’ (0.20) are almost equal in importance while ‘minimizing excavation’ (0.48) received the highest score. The ‘soil erosion risk’ and the need for ‘rock blasting’ are mostly site-specific; hence, measures are required to minimize the damages rather than to eliminate such activities. But excavation works can be minimized and sometimes avoided. As Interviewee 4 stated:

> *“Some projects use penstocks laid on brackets rather than channels or tunnels and that way excavation works can be avoided up to some extent.”*

λ max = 3.00=3 (number of factors) means that there are no errors in the calculations and CR = 0.00 (CR < 0.1 means that the values are consistent at 10% random values).

9.5.3. Minimizing Usage of Materials in terms of Quantity (ES2a)

As shown in Section 8.4.2, materials shortages are likely to occur in the country in the near future and all types of infrastructure projects can contribute to minimizing the grave implications of this prospective shortage. SHP projects are small-scale projects where materials consumption during the operation stage is negligible, but should be considered during the construction stage. Since impacts related to ES2a were not indicated in the field survey, experts were asked which materials should be considered in assessing usage of materials in SHP projects. Based on expert opinion, it was decided to consider aggregates, timber and water as these are the most used materials in SHP projects while materials such as cement, finishing materials for power house and so on were considered together as ‘other construction materials’. Two methods can be used to minimize the usage of materials: reduction and reuse. Figure 9-4 illustrates these aspects. The calculation of weightings is shown in Table 9-6 and Table 9-7. The design and planning of projects can be done carefully to ‘reduce’ the usage of these materials. However, due to the small scale of the projects, only ‘timber’ and ‘aggregates’ were seen as carrying with them the possibility of reuse.

The usage of aggregates has been identified as the most notable with a normalized weight of 0.48 followed by timber (0.22), other construction materials (0.22), and water (0.08). As Interviewee 3 stated:

“Compared to other types of materials, availability of water is not a problem in these projects but unnecessary usage should be controlled.”

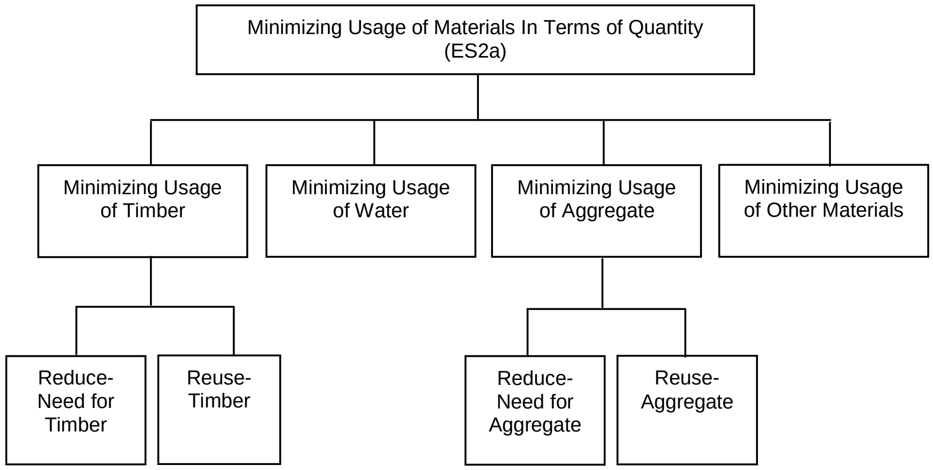

Figure 9-4: Material Usage Issues (in terms of quantity – ES2a) in SHP projects

The option ‘reusing’ received higher scores for both ‘timber’ (0.84) and ‘aggregates’ (0.63) in comparison with ‘reducing’, the need for ‘timber’ and ‘aggregates’ (0.16 and 0.37 respectively). According to Interviewee 7:

“Timber used for temporary works can be re-used. Excavated materials and blasted boulders and excavated sand can be re-used too within the project.”

Table 9-6: Weightings of Materials Usage Issues (in terms of quantity – ES2a) in SHP projects

	Timber	Water	Aggregates	Other Materials	Normalized Weight	λ max
Timber	**1.00**	3.24	0.41	0.87	**0.22**	4.03
Water	0.31	**1.00**	0.16	0.45	**0.08**	4.04
Aggregate	2.41	6.33	**1.00**	1.93	**0.48**	4.01
Other Materials	1.15	2.21	0.52	**1.00**	**0.22**	4.04
					1.00	4.03

λ max = 4.03>4 (number of factors) means that there are no errors in the calculations and that values can be used to calculate the Consistency Index (CI).

Consistency Index (CI) = $(\lambda max - n)/(n - 1)$

= $(4.03– 4)/(4 -1)$

= 0.0099

Consistency Ratio (CR) = CI/RI

For number of factors = 4, RI = 0.89 (from random matrices table for N= 4) (see Table 7-3)

Consistency Ratio (CR) = 0.0099/ 0.89

= 0.011< 0.1

CR < 0.1 means that the values are consistent at 10% random values.

Table 9-7: Weightings for Timber and Aggregate Usage

	Reduce - Need for Timber	Reuse - Timber	Normalized Weight
Reduce –Need for Timber	**1.00**	0.20	**0.16**
Reuse - Timber	5.12	**1.00**	**0.84**
			1.00

	Reduce Need for Aggregate	Reuse Aggregate	Normalized Weight
Reduce –Need for Aggregate	**1.00**	0.59	**0.37**
Reuse - Aggregate	1.68	**1.00**	**0.63**
			1.00

9.5.4. Minimizing Impacts during Extraction of Materials (ES2b)

With regard to the issue of source of materials, only two types of materials, ‘timber’ and ‘aggregate,’ were treated as important in SHP projects. While timber can be extracted from sustainable sources such as ‘planted forests,’ ‘aggregates’ also can be obtained from ‘sustainable sources’. Figure 9-5 illustrates these options in a hierarchical structure. Table 9-8 presents the calculation of weightings.

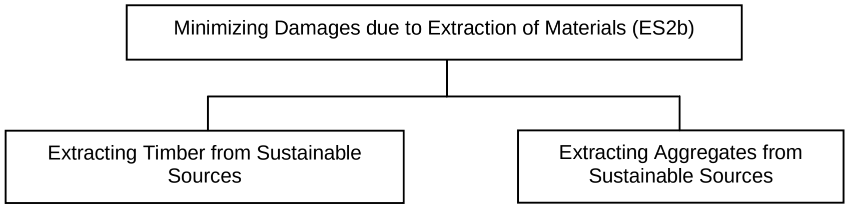

Figure 9-5: Materials Usage Issues (in terms of damages during extraction – ES2b) in SHP projects

Extracting aggregates from sustainable sources (0.71) is of higher importance than timber extraction (0.29). This is due to the higher extent of usage of aggregates in SHP projects and the issues that Sri Lanka currently faces due to unsustainable usage of aggregates. However, as Interviewee 5 put it:

> *"Sometimes the developers do not have access to information on the sources of materials. They purchase from intermediate suppliers but may not purchase from the source of extraction. But it should be encouraged to consider and demand for sustainable sources."*

Table 9-8: Weightings of Materials Usage Issues (in terms of damages during extraction – ES2b) in SHP projects

	Extracting Timber from Sustainable Sources	Extracting Aggregates from Sustainable Sources	Normalized Weight
Extracting Timber from Sustainable Sources	**1.00**	0.41	**0.29**
Extracting Aggregates from Sustainable Sources	2.41	**1.00**	**0.71**
			1.00

9.5.5. Minimizing Impacts during the Usage of Materials (ES2c)

Harmful types of materials or harmful usage of materials were not observed in SHP projects during the field survey or the interviews with experts. Hence, factors under ES2c were not used for further analysis.

9.5.6. Minimizing Usage of Non-Renewable Energy (NRE) Sources in terms of Quantity (ES3a)

Similar to issues encountered under "Usage of materials" (ES2), the impacts related to ES3 were not indicated in the field survey. Therefore, the experts were asked to indicate the usages that should be considered when assessing SHP projects. Although the usage of NRE sources is not extensive in SHP projects, fuel and electricity consumption during construction were taken into consideration in the study as shown in Figure 9-6. The calculation of weightings is shown in Table 9-9.

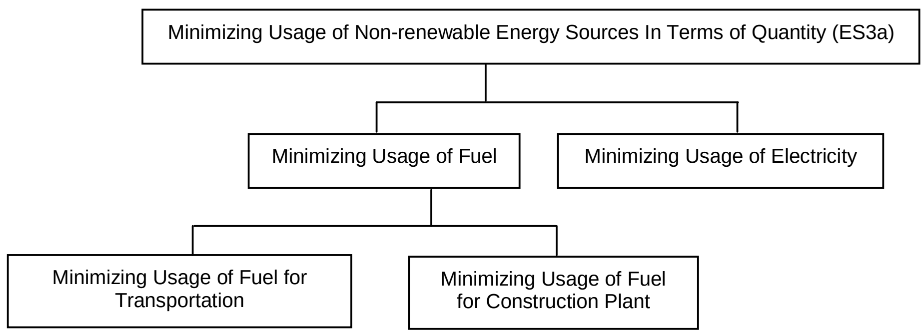

Figure 9-6: Issues under the Usage of Non-renewable Energy Sources (in terms of quantity – ES3a) in SHP projects

The results showed that 'fuel consumption' (0.75) is considerably higher than 'electricity consumption' (0.25) in SHP projects.

The results also showed that minimising fuel consumption for 'transportation' (0.76) is of higher importance than for 'construction plant and machinery' (0.24). As Interviewee 8 stated:

> *"Fuel usage for transportation is considerable since most of the SHP projects are located in remote areas. Materials and other equipment should be transported long distances. Also in SHP project locations, electricity is generated using portable generators due to the absence of a power supply from the national grid. Hence, sometimes the fuel consumption includes electricity generation as well"*

Table 9-9: Weightings of Issues under Usage of NRE Sources (in terms of quantity – ES3a) in SHP projects

	Usage of Fuel	Usage of Electricity	Normalized Weight
Usage of Fuel	**1.00**	2.99	**0.75**
Usage of Electricity	0.33	**1.00**	**0.25**
			1.00

	Transportation	Construction Plant	Normalized Weight
Transportation	**1.00**	3.21	**0.76**
Construction Plant	0.31	**1.00**	**0.24**
			1.00

9.5.7. Minimizing Impacts during Extraction of Non-Renewable Energy (NRE) Sources (ES3b)

SHP developers are not concerned about the sources of non-renewable energy both because these sources are imported to the country and due to the small-scale of the projects, which bring down the scale of consumption. Moreover, neither the source nor the details of impacts during extraction are available to SHP developers. Such issues are more relevant to large scale projects which use NRE sources extensively, for example, thermal power projects. The experts too agreed pointing out that, given the relatively low quantity of usage of NRE sources in SHP projects, the developers cannot be expected to take into consideration the source of NRE and their impacts on the environment during extraction. Therefore, the factors under ES3b were not considered for further analysis.

9.5.8. Minimizing Impacts during Usage of Non-Renewable Energy (NRE) Sources (ES3c)

SHP projects utilized NRE sources mainly for the operation of construction equipment and transportation. Neither harmful types of NRE sources nor harmful usage of NRE were observed in SHP projects either during the field survey or during interviews with the experts. Therefore, the factors under ES3c were not considered in the study for further analysis.

9.5.9. Minimizing Waste Disposal in terms of Quantity (ES4a)

Generally, there are many types of waste arising from a construction site such as construction waste (excavated materials, excess materials), storage bags/containers, and waste generated by the workforce. The experts noted that although the amount of waste generated in SHP projects is not extensive, excavated materials and construction waste can be "reduced" through different strategies and the generated wastes can be "re-used" where possible. Figure 9-7 illustrates these options in the hierarchical structure. Table 9-10 gives the calculation of weightings.

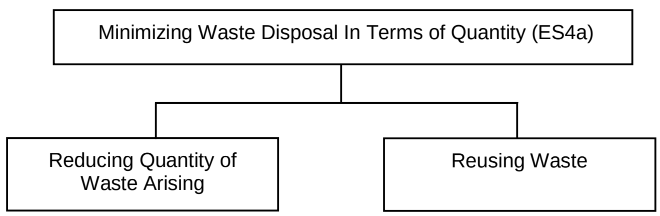

Figure 9-7: Waste Disposal Issues (in terms of quantity – ES4a) in SHP projects

As Section 9.5.3 also shows under usage of materials, the option of 'reusing' (0.78) is preferable in the case of waste issues as well. This is because waste generation cannot always be eliminated in construction. Hence, reusing is a better option to minimize waste disposal.

Table 9-10: Weightings of Waste Disposal Issues (in terms of quantity – ES4a) in SHP projects

	Reducing Quantity of Waste arising	Reusing Waste	Normalized Weight
Reducing quantity of Waste arising	**1.00**	0.28	**0.22**
Reusing Waste	3.56	**1.00**	**0.78**
			1.00

9.5.10. Improving the Quality of Waste before Disposal (ES4b)

Neither the field survey nor interviews with experts revealed any waste types in SHP projects that are harmful to the environment and that therefore need to be improved in terms of quality before disposal. Therefore, the factors under ES4b were not considered for further analysis in the study.

9.5.11. Disposal of Waste in a Proper Location (ES4c)

Since most SHP locations are in forest areas and projects are always located near a water source, waste should be disposed of with care. The field survey showed the following issues related to waste disposal location: dumping of excavated materials on river banks, dumping waste in nearby lands, and the risk of oil leakages in emergency situations (see Table 9-3). Waste should be stockpiled and disposed of in an appropriate manner and necessary preventive measures should be taken to reduce the risk of oil leakages into the river during emergencies. Figure 9-8 illustrates the location issues related to waste disposal in SHP projects while Table 9-11 presents the calculation of weightings.

'Preventing Waste Disposal to the River' received the highest score (0.74), which was considerably higher than that for 'Disposal into Nearby Lands' (0.20). 'Preventing Oil Leakages' (0.07) received the least priority. According to Interviewee 6:

> *"Preventing waste being added to the river is necessarily required in SHP projects since it is detrimental to the aquatic ecosystem. Also if the excavated materials are not carefully disposed of, it causes soil erosion and siltation consequently. There are projects that transport excavated materials directly to villagers' home gardens and agricultural lands for their usage. These arrangements are made properly and prior to starting excavation. So there is no requirement to dump elsewhere."*

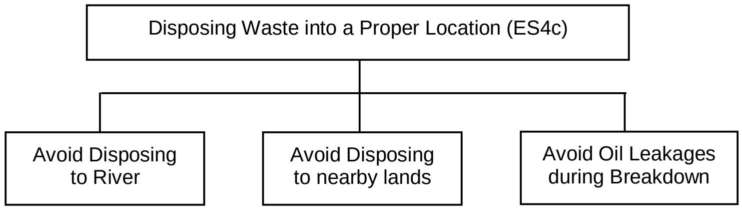

Figure 9-8: Waste Disposal Issues (in terms of location – ES4c) in SHP Projects

Emergency oil leakages are not yet reported in the country's SHP sector. However, there is the possibility of such an eventuality. Hence, preventive measures should be incorporated into SHP projects. As Interviewees 10 put it:

"Although not reported yet in Sri Lanka, SHP developers should make necessary arrangements to prevent oil substances mixing with the river during an emergency situation since it is detrimental to the aquatic ecosystem."

Interviewee 7 too expressed similar sentiments:

"Although not commonly known, there is a possibility of emergency blasts and oil leakages. Some projects adopt the proper systems to avoid such impacts."

Table 9-11: Weightings of Waste Disposal Issues (in terms of location – ES4c) in SHP Projects

	Avoid Disposing River	Avoid Disposing to Nearby Lands	Avoid Oil Leakages	Normalized Weight	λ max
Avoid Disposing River	**1.00**	5.05	8.19	**0.74**	3.09
Avoid Disposing to Nearby Lands	0.20	**1.00**	4.00	**0.20**	3.09
Avoid Oil Leakages	0.12	0.25	**1.00**	**0.07**	3.09
				1.00	3.09

λ max = 3.09>3 (number of factors) means that there are no errors in the calculations and that values can be used to calculate the Consistency Index (CI).

Consistency Index (CI)	=	(λmax - n)/(n - 1)
	=	(3.09– 3)/(3 -1)
	=	0.0455
Consistency Ratio (CR)	=	CI/RI

For number of factors = 3, RI = 0.52 (from random matrices table for N= 3) (see Table 7-3)

Consistency Ratio (CR)	=	0.0455/ 0.52
	=	0.0875< 0.1

CR < 0.1 means that the values are consistent at 10% random values.

9.5.12. Investment in Natural Capital – to Maintain Natural Capital Stock (ES5a)

During operations, clearance and maintenance activities are carried out periodically to clear mud and waste near the weir and the intake. Furthermore, the project team should take measures to identify and avoid the spread of invasive species in order to maintain the quality of the natural capital stock in the area. Figure 9-9 illustrates these issues in the form of a hierarchical structure while Table 9-12 shows the calculation of weightings.

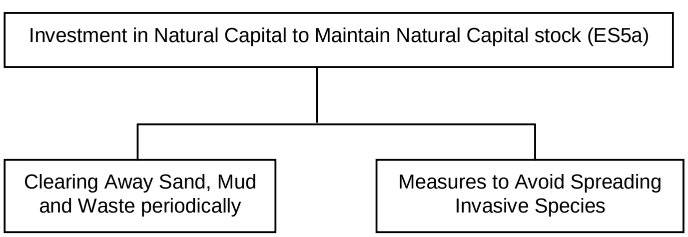

Figure 9-9: Ways to Invest in Natural Capital (to Maintain Natural Capital Stock) in SHP projects

Here, “Clearing away sand, mud and waste” (0.78) received more emphasis than “Preventing invasive species’ (0.22). As Interviewee 11 put it:

"Spread of invasive species is a considerable issue in large scale projects though impacts are fewer in the small construction sites of SHP projects."

According to Interviewee 6:

"The information flow and knowledge about invasive species are lacking. So government authorities should get involved in such issues with the cooperation of experts in the field. Hence, it is hardly the developer's responsibility. However, it is better to consider this issue in environmental assessments and monitoring as well and also to raise awareness."

Table 9-12: Weightings of Ways to Invest in Natural Capital (to Maintain Natural Capital Stock) in SHP projects

	Clearing Away Sand, Mud and Waste	Preventing Invasive Species	Normalized Weight
Clearing Away Sand, Mud and Waste	**1.00**	3.46	**0.78**
Preventing Invasive Species	0.29	**1.00**	**0.22**
			1.00

9.5.13. Investment in Natural Capital – to Enhance Natural Capital Stock (ES5b)

Some projects carry out tree plantations in the surrounding areas. This can be done either as compensation for lost vegetation or for enhancement of the surrounding environment. As indicated in Table 9-3, plantations are helpful in maintaining water retention in these areas. However, the developers may not necessarily pay attention to the type of plantations in such efforts whereas the preservation of affected species is important to avoid loss of species and to enhance species. Thus, preservation and enhancement measures require additional effort by the project teams. Experts considered these efforts under ES5b, "Investment to enhance natural capital stock". Figure 9-10 illustrates these aspects under ES5b in a hierarchical structure. Table 9-13 gives the calculation of weightings.

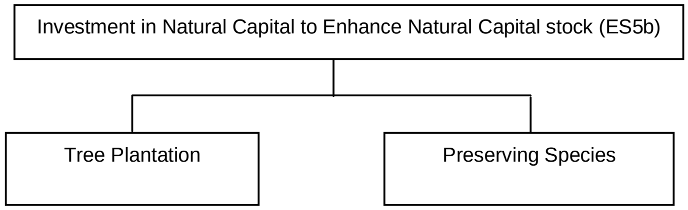

Figure 9-10: Ways to Invest to Enhance Natural Capital Stock in SHP projects

'Preservation of Affected Species" (0.58) received more emphasis in comparison with 'Tree Planting' (0.42). This is because some affected species are endemic fauna species and, thus, once they lose their habitats, the species can become extinct. It is the same with some flora species. Hence, efforts by developers to avoid such losses should be assigned a higher score. As Interviewee 4 put it:

> *"In a recent SHP project, after the blasting activities, a dead fish was found and it was reported as an endangered species. Therefore, proper studies should be carried out prior to the start of construction activities and if there are any affected species, they should be preserved. Clearance of forest areas also affects some endemic flora species."*

Planting trees in surrounding areas is a good practice that some SHP developers are carrying out. So Interviewee 6 stated that:

> *"we maintain nurseries to plant trees just after construction and the species are selected carefully to suit the locality. Interaction with villagers is important here because they know which flora species are suitable for the area."*

Table 9-13: Weightings of Investment in Natural Capital (to Enhance Natural Capital Stock) in SHP projects

	Tree Plantation	Preserving Species	Normalized Weight
Tree Plantation	1.00	0.72	**0.42**
Preserving Species	1.38	1.00	**0.58**
			1.00

9.5.14. Conserving Biodiversity (ES6)

In the field survey, several impacts on biodiversity due to SHP projects were identified. These impacts included adverse impacts to both aquatic and terrestrial ecosystems, including both flora and fauna species. Experts proposed several strategies to avoid these impacts such as avoiding losses where possible; minimizing losses if it is not possible to avoid losses; and compensating for losses. Compensation of losses included efforts to preserve affected species. These strategies are helpful in protecting available species. There are also opportunities to enhance species where possible. As indicated in Table 9-3, these strategies should be considered during the different stages of SHP projects from site selection and construction to operation. In addition to addressing loss of species, preventing invasive species is also important to avoid harmful impacts on biodiversity in the area due to construction sites. These efforts are illustrated in Figure 9-11 while calculation of weightings is given in Table 9-14.

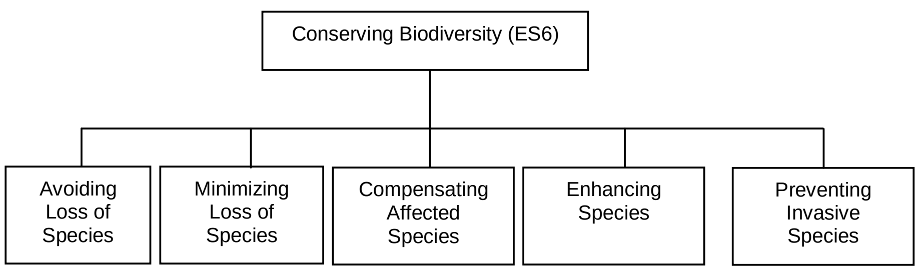

Figure 9-11: Biodiversity Issues in SHP projects

‘Enhancing Species’ (0.54) was preferred to the other options and received the highest score followed by ‘Avoiding Loss of Species’ (0.22). According to Interviewee 2:

> *“It is better if the project team is able to enhance or avoid loss of species but where it is not practical to avoid loss, compensation is the next solution though protecting the natural properties of ecosystems is the preferred option.”*

Table 9-14: Weightings of Biodiversity Issues of SHP projects

	Avoiding	Minimizing	Compensating	Enhancing	Preventing Invasive Species	Normalized Weight	λ max
Avoiding	**1.00**	4.70	2.33	0.28	5.19	**0.22**	5.18
Minimizing	0.21	**1.00**	0.20	0.14	2.10	**0.05**	5.32
Compensating	0.43	5.04	**1.00**	0.16	5.05	**0.15**	5.46
Enhancing	3.59	7.32	6.07	**1.00**	7.82	**0.54**	5.43
Preventing Invasive Species	0.19	0.48	0.20	0.13	**1.00**	**0.04**	5.33
						1.00	5.34

λ max = 5.34>5 (number of factors) means that there are no errors in the calculations and that values can be used to calculate the Consistency Index (CI).

Consistency Index (CI) = $(\lambda max - n)/(n - 1)$

= (5.34–5)/(5 -1)

= 0.0858

Consistency Ratio (CR) = CI/RI

For number of factors = 5, RI = 1.11 (from random matrices table for N= 5) (see Table 7-3)

Consistency Ratio (CR) = 0.0858/ 1.11

= 0.077< 0.1

CR < 0.1 means that the values are consistent at 10% random values.

9.5.15. Contributions to Eradicate Poverty (ES7)

Though SHP projects are small-scale projects, they can contribute to the socio-economic growth of the locality in several ways as revealed in the field survey. Many of the SHP projects are located in rural areas where the major income generation activities are either in small-scale agriculture or as labourers in factories or farms, sometimes on a part-time basis. In many areas, the quality of life is affected by the lack of infrastructure facilities in the area. Figure 9-12 illustrates the possible contributions of SHP projects to socio-economic issues in the locality. Table 9-15 gives the calculation of weightings.

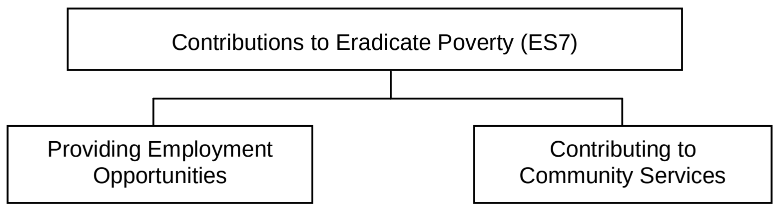

Figure 9-12: Contributions in SHP projects to Eradicate Poverty

'Contributing to community services' received higher scores (0.61) in comparison with 'Providing Employment Opportunities' (0.39).

Table 9-15: Weightings of Contributions in SHP projects to Eradicate Poverty

	Providing Employment Opportunities	Community Services	Normalized Weight
Providing Employment Opportunities	**1.00**	0.64	**0.39**
Community Services	1.57	**1.00**	**0.61**
			1.00

In the opinion of Interviewee 1:

> *"SHP projects can provide many employment opportunities during construction and it will be a socio-economic contribution to the locality. However, during operation, only a few staff members will be there. So, not many opportunities for work are available. With many SHP projects,*

community services are provided for the locality including improving the existing facilities, and social welfare programs. While these are helpful as socio-economic impacts, they help with better interactions between the project team and the locals."

9.5.16. Compliance with Environmental Laws and Standards (ES8)

Both illegal logging and animal poaching are grave issues faced by construction sites located in ecologically valuable areas. Generally, because of water diversion into channels, the water flow is less than earlier in the river stretch between the intake and the tail race discharge. However, environmental authorities specify a minimum water flow for each project in order to minimize the adverse impacts. Thus, another issue specific to SHP projects is the non-compliance with legislation to maintain this minimum environmental flow. Figure 9-13 illustrates these legal issues in a hierarchical structure. Table 9-16 gives the calculation of weightings.

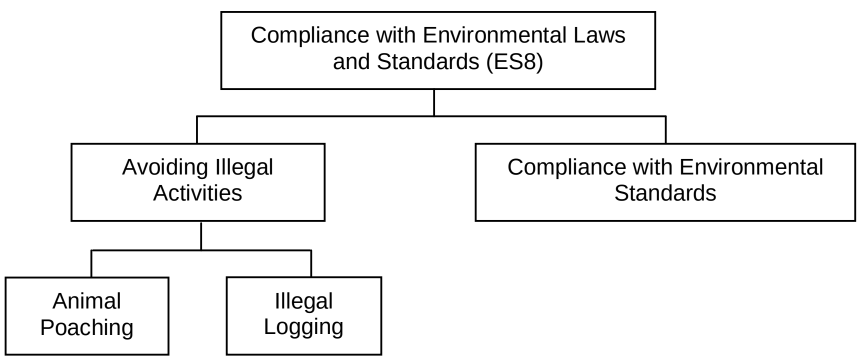

Figure 9-13: Compliance Issues in SHP projects

'Compliance with Environmental Standards' (0.67) received higher scores compared to 'Avoiding Other Illegal Activities' (0.33). The dryness of the water stretch between the intake and the tailrace discharge was the issue most noted during the field survey. Hence, compliance with environmental flow is a major requirement in SHP projects.

As Interviewee 3 put it:

"Non-compliance with environmental flow causes negative impacts to aquatic species and for terrestrial species in the river banks and nearby

areas. This is inevitable, and also the distance of this river stretch depends on the weir location and tail race discharge which is determined based on the water head. Minimum flow should be maintained as a solution as well as a requirement. However, in some SHP projects, this is not followed and in the dry season where the minimum flow is necessary, water flow is sometimes blocked artificially and illegally to increase the water intake. It is becoming a serious issue too as the numbers of projects continue to increase."

Table 9-16: Weightings of Compliance Issues in SHP projects

	Compliance with Environmental Standards	Avoiding Illegal Activities	Normalized Weight
Compliance with Environmental Standards	**1.00**	1.99	**0.67**
Avoiding Illegal Activities	0.50	**1.00**	**0.33**
			1.00
	Illegal Logging	Animal Poaching	Normalized Weight
Illegal Logging	**1.00**	2.31	**0.70**
Animal Poaching	0.43	**1.00**	**0.30**
			1.00

9.6. Calculations of Final Weightings of the Factors Assessing SHP Projects

Environmental impacts of SHP projects were analysed for their relative importance under each ES factor. These impacts were analysed using the AHP technique in several hierarchical structures. To obtain the final weightings for each SHP factor, normalized weighting of each SHP factor should be multiplied by the final weighting of the factor to which it is linked in the immediate higher level of the hierarchical structure. This is because, in the AHP technique, the weighting of each factor is distributed among several lower level factors that are linked to the particular factor.

For example, under the main factor ES1, there are two sub factors, namely, ES1a and ES1b, with impacts of SHP projects identified under both sub-factors. In Chapter 8, the weightings of each ES factor were calculated, the weighting of ES1 being 0.092 (see Table 8-7). This weighting was distributed among ES1a and ES1b according to their relative importance resulting in 0.035 and 0.056 respectively. As shown in Figure 9-2 and Figure 9-3, these weightings are distributed among SHP factors under ES1a and ES1b according to their relative importance. For example, there are two SHP factors under ES1, namely, "minimizing submerged area" and "minimizing area used for other project components" with normalized weights of 0.422 and 0.578 respectively (see Table 9-4). These normalized weights should be multiplied by weighting of ES1a (0.035) to obtain their final weightings.

No impacts were identified related to SHP projects under sub-factors ES2c, ES3b, ES3c and ES4b. Although SHP projects do not cause impacts or cause only negligible impacts under these issues, holding the view that ERSs should assess the real project performance rather than rewarding inherent features of project types, the weightings of the main ES factors were re-distributed only among available sub-factors. Thereafter, the same calculations process was applied as explained above.

The calculations and the individual hierarchical structures of each ES factor are given in Appendix 5. The final weightings of all SHP factors based on these hierarchical structures for the application of the conceptual framework for the SHP sector are presented in Figure 9-14.

9.7. Summary

The chapter demonstrated the application of the proposed conceptual framework for developing type-specific ERSs in the infrastructure sector in Sri Lanka, by applying it into the SHP sector. It also presented the findings of the field survey conducted in the vicinities of SHP projects in Sri Lanka. The field survey, which included informal interviews with the general public in the areas in which SHP projects are located, identified both the environmental problems as well as the positive impacts of SHP projects. A list of such issues were identified and thereafter validated during interviews with experts in the field. The recommended solutions by the experts were listed and the experts were requested to indicate the relevant ES factors. The hierarchical levels under each ES factor were developed and a questionnaire prepared accordingly. The chapter presented the results of the analysis of the responses to the questionnaire using the AHP technique. The chapter also included discussions of the results together with the findings from the interviews with the experts. The chapter identified the specific issues that determine the environmental sustainability of Sri Lankan SHP projects.

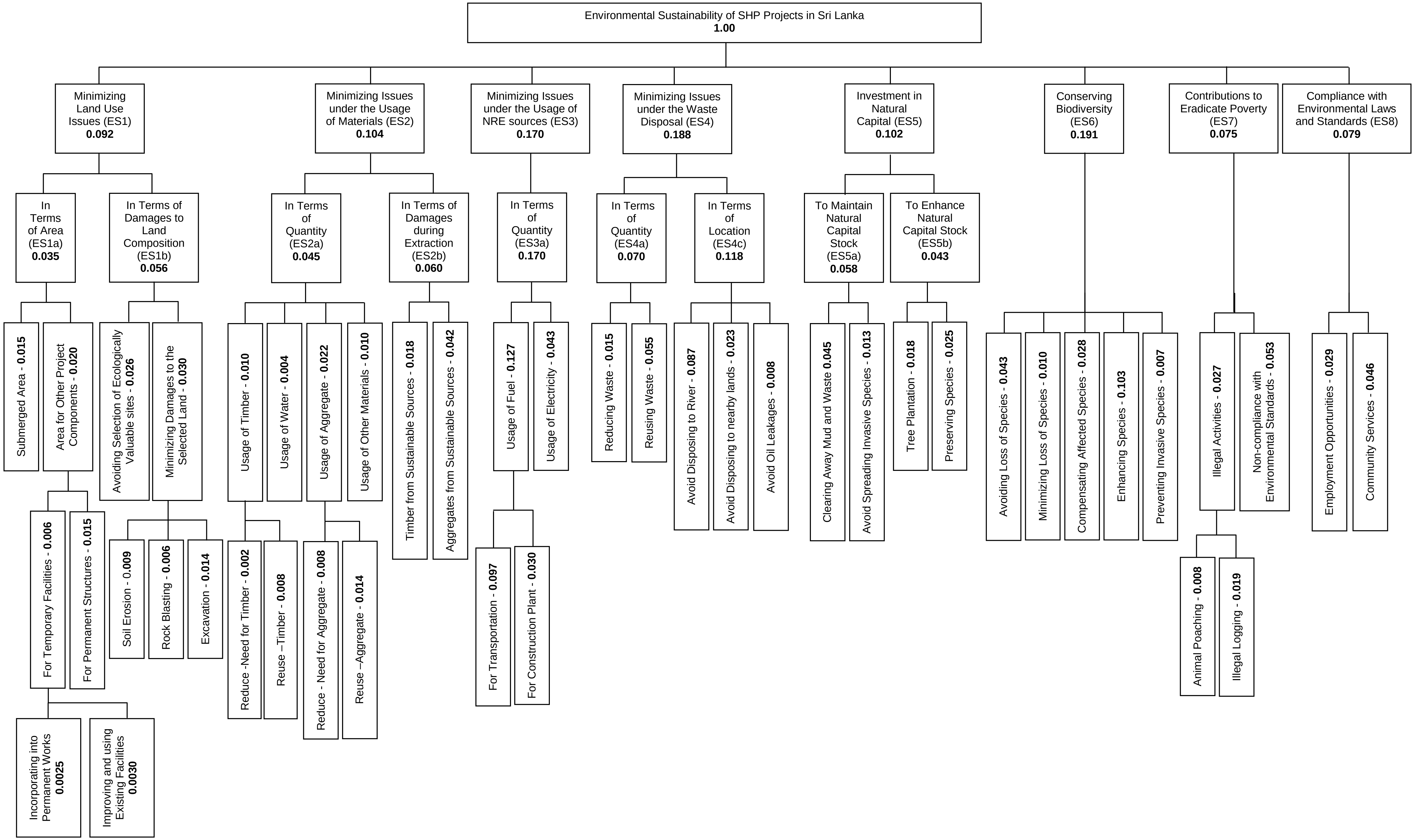

Figure 9- 14: Application of the Conceptual Framework to SHP Projects

Chapter 10: Discussion of Results and Findings

10.1. Introduction

The study proposed a conceptual framework for ERSs for assessing infrastructure projects in Sri Lanka. This conceptual framework included the factors that should be considered in assessing the environmental sustainability of infrastructure projects and the relative importance of those factors. This chapter offers a comparison between the proposed framework and other infrastructure-related ERSs. The chapter then discusses the main findings from the survey and recapitulates the interviews and literature review in order to supplement these findings.

10.2. Comparison of Conceptual Framework with Existing ERSs for assessing infrastructure projects

Chapter 4 presented the details of existing ERSs for infrastructure projects and compared their respective criteria and weightings. Figure 10-1 compares the factors of existing ERSs with those of the proposed conceptual framework. This section draws attention to the main points of this comparison.

10.2.1. Ecology and Biodiversity

Under the aspect of “Ecology and Biodiversity”, composite weightings of “Conserving Biodiversity” (ES6) and “Investment in Natural Capital” (ES5) were used for the purpose of the comparison. It reveals a significantly higher weighting in the proposed framework compared to other ERSs, under the category of “Ecology and Biodiversity” in fact receiving the highest rank in the conceptual framework. A composite category was used in the comparison because other ERSs do not include a separate category that is similar to ES5 in the present framework. However, the IS rating scheme allocates 3% of total points to reward maintenance or enhancement of ecological value under the main category of “Ecology”. Also the BCA Green Mark scheme allocates 2-3% of total points for improvement in Greenery areas and encourages the transplantation of trees. In the CEEQUAL scheme, around 4% of the total score is allocated for improving land quality, wildlife habitats and the water environment. Though the Envision scheme does not address such issues explicitly in the criteria list, the point system allocates more points for enhanced performance in each criterion in order to capture such practices. Nevertheless, the proposed conceptual framework pays more attention to ecology and biodiversity aspects compared to the existing systems.

Section 6.4.4 explained both the requirement as well as the importance of investing in natural capital for the long-term survival of species and the natural environment. As explained in Section 6.4.5, biodiversity is a valuable natural property of ecosystems and infrastructure development, as mentioned in Section 4.2, is one of the main pressures on biodiversity. Moreover, as Chapter 6 put it, the sustainability of everything else depends on the sustainability of the natural environment. Therefore, conserving biodiversity and investing in natural capital are important for the survival of the natural environment, hence, the need for sustainability. The role of ERSs is to assess the performance of projects with regard to environmental sustainability. Thus, it is important to pay more attention to ecological value, biodiversity and natural capital through ERSs, which is why the proposed conceptual framework pays attention to these aspects.

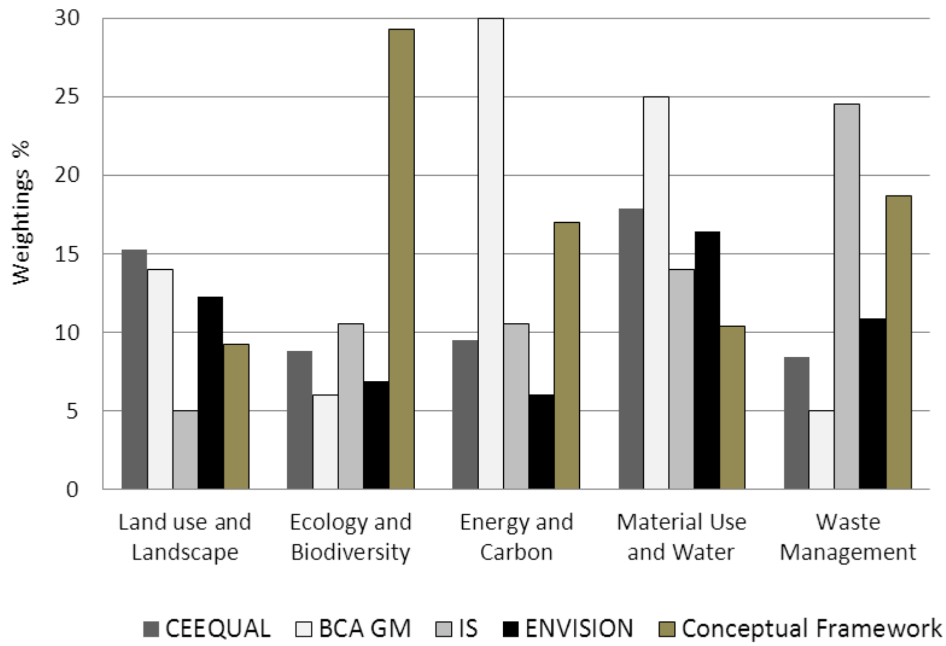

Figure 10-1: Comparison of Proposed Conceptual Framework with Existing ERSs

10.2.2. Socio-economic Barriers to Environmental Sustainability

The proposed conceptual framework addressed the socio-economic barriers to environmental sustainability such as poverty under ES7. However, the other ERSs do not address this issue. One reason for this could be that the other ERSs were launched in developed countries (UK, Singapore, Australia and US) whereas the proposed conceptual framework is for the developing countries where socio-economic barriers stand in the way of efforts to achieve environmental sustainability. Instead of socio-economic problems, the existing ERSs address social issues such as quality of life and community well-being. This difference can be attributed to differences in priorities with regard to development in the developed and developing regions as explained in Chapter 6.

10.3. Comparison with the Environmental Rating System in Sri Lanka

There are no ERSs for infrastructure assessment in Sri Lanka so far. However, GBCSL (2011) published a green rating system to assess buildings in Sri

Lanka. Figure 10-2 offers a comparison between this rating system and the proposed conceptual framework in terms of criteria common to both. To take land use first: the GBCSL system considers land use issues under the category 'sustainable sites' while the weighting for land use in the proposed conceptual framework is significantly higher than that of the GBCSL system. This can be attributed to the fact that land use for infrastructure is significantly higher than that for buildings.

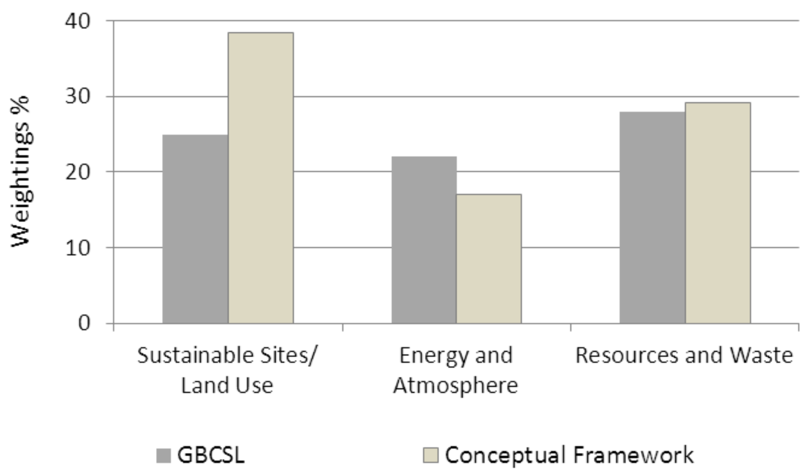

Figure 10-2: Comparison between GBCSL Rating System and Proposed Conceptual Framework

With regard to 'Waste Management', GBCSL does not consider it separately but under materials and resources. The composite weightings for resource and waste in GBCSL are almost similar to the total weightings of "Waste Disposal" (ES4) and "Usage of Materials" (ES2) in the proposed conceptual framework. This reflects similar regional priorities. Under the aspects of energy and atmosphere, the weighting of the GBCSL system is slightly higher than that in the proposed conceptual framework. This can be attributed to the fact that energy use in buildings is considerably higher compared to that of many infrastructure project types. Hence, the comparison of weightings suggests that both systems have similar regional priorities despite the fact that the two systems concern themselves with sectors that have many differences between them: buildings and infrastructure.

10.4. Main Findings and Discussion

10.4.1. Conceptual Framework for ERSs for Assessing Infrastructure Projects in Sri Lanka

The study developed a conceptual framework for ERSs for assessing infrastructure projects in Sri Lanka. ERSs evaluate and measure the performance of projects with regard to sustainability. Table 10-1 lists the ES factors identified in the study that are required for Sri Lankan infrastructure projects to achieve environmental sustainability according to the weightings they received in the survey. It gives the basis for developing ERSs for Sri Lankan infrastructure projects. This section highlights and discusses the key results, supplementing them with interview findings and insights elicited from the literature review.

Table 10-1: Factors Determining Criteria and Weightings in the Conceptual Framework

Factors Determining Criteria		**Weightings %**	
1	Conserving Biodiversity (ES6)		19.10
2	Minimizing Waste Disposal Issues (ES4)		18.80
2.1	In Terms of Quantity (ES4a)	4.4	
2.2	In Terms of Improving the Quality before Disposal (ES4b)	7.1	
2.3	Ensuring Disposal in a Proper Location (ES4c)	7.2	
3	Minimizing Usage of Non-renewable Energy Sources (ES3)		17.00
3.1	In Terms of Quantity (ES3a)	6.6	
3.2	In Terms of Impacts during Extraction (ES3b)	5.4	
3.3	In Terms of Impacts during Usage (ES3c)	4.9	
4	Minimizing Usage of Materials (renewable) (ES2)		10.40
4.1	In Terms of Quantity (ES2a)	3.0	
4.2	In Terms of Impacts during Extraction (ES2b)	4.1	
4.3	In Terms of Impacts during Usage (ES2c)	3.4	
5	Investing in Natural Capital (ES5)		10.20

5.1	To Maintain the Natural Capital Stock (ES5a)	5.8	
5.2	To Enhance the Natural Capital Stock (ES5b)	4.3	
6	Minimizing Land Use (ES1)		9.20
6.1	In terms of Land Area (ES1a)	3.5	
6.2	In terms of Damages to Land Composition (ES1b)	5.6	
7	Compliance with Environmental Laws and Regulations (ES8)		7.90
8	Contributions to Eradicate Poverty (ES7)		7.50
TOTAL			**100.00**

The survey results suggested that “Conserving Biodiversity” (ES6) is the most important factor to be considered in assessing the environmental sustainability of infrastructure projects in Sri Lanka. The interviews supplemented this result. As highlighted in the literature review, some of the losses of biodiversity are irrecoverable and the interviewees too emphasized the risk and, hence, the importance of paying attention to biodiversity conservation in infrastructure development. This factor is more important in Sri Lanka today due to the rapid growth in infrastructure development which is spreading right throughout the country employing large land areas, some of which can be designated as ecologically sensitive.

The survey results identified “Waste Disposal” (ES4) as the second most severe problem that should be considered in assessing infrastructure projects in Sri Lanka. The interviewees supplemented this result by highlighting the severe problem of waste that the country is facing today, especially given the difficulty in finding proper locations to dispose of waste. As explained via the application of the laws of thermodynamics into environment-economic interactions in the literature review, waste cannot be eliminated. Hence, it is important to minimize the quantity and the harm of the disposed of waste. The point highlighted in the literature review that solid waste is mostly associated with demolition waste in developing countries was supplemented in the interviews where too it was mentioned that demolition waste is the major solid waste issue in the Sri Lankan construction industry.

According to the literature review, non-renewable fossil fuel usage has increased over the past two decades in the Sri Lankan power sector which leads to an increase in its overall use in the country as well. Interviewees confirmed that "Usage of Non-Renewable Energy Sources" (ES3) is showing an increasing trend. Although the problem may not be as severe as those classified under ES6 and ES4 at the moment, that it would cause severe problems in the near future. Reflecting this relative importance, it received the third highest weightings.

Two socio-economic factors were considered in the conceptual framework, namely, "Contributions to Eradicate Poverty (ES7)" and "Compliance with Environmental Laws and Standards (ES8)." These two factors received the least weightings among the eight major factors considered. It suggests that in ERSs, ecological aspects should be given priority though socio-economic issues too should be addressed up to a certain extent. This result supplements the inclusion of socio-economic barriers in environmental sustainability in the proposed conceptual framework for ERSs in the infrastructure sector of Sri Lanka.

10.4.2. Application of the Proposed Framework to the SHP Sector

The application of the conceptual framework developed to the SHP sector in Sri Lanka helped to highlight both the negative and positive impacts of SHP projects in Sri Lanka under each ES factor in the conceptual framework. The survey results showed the relative importance of each factor in the Sri Lankan context. The final weightings of issues identified in SHP projects are presented in Table 10-2. Factors are listed in the descending order of main ES factors.

Table 10- 2: Application of the Conceptual Framework to the SHP sector

Factors Determining Criteria		**Relative Importance %**		
1	**Conserving Biodiversity (ES6)**			**19.10**
a)	*Avoiding loss of species*	4.30		
b)	*Minimizing Loss of Species*	1.00		
c)	*Compensating Affected Species*	2.80		

d)	*Enhancing species*	10.30		
e)	*Preventing Invasive Species*	0.70		
2	**Minimizing Waste Disposal Issues (ES4)**			**18.80**
2.1	In Terms of Minimizing the Quantity (ES4a)		7.00	
a)	*Reducing Quantity of Waste Arising*	1.50		
b)	*Reusing Waste Generated*	5.50		
2.2	Ensuring Disposal in a Proper Location (ES4c)		11.80	
a)	*Avoiding Adding to River*	8.70		
b)	*Avoiding Disposing to Nearby Lands*	2.30		
c)	*Avoiding Oil Leakages during Breakdown*	0.80		
3	**Minimizing Usage of Non-Renewable Energy Sources (ES3)**			**17.00**
3.1	In Terms of Quantity (ES3a)		17.00	
a)	*Minimizing Usage of Fuel for Transportation*	9.70		
b)	*Minimizing Usage of Fuel for Construction Plant*	3.00		
c)	*Minimizing Usage of Electricity*	4.30		
4	**Minimizing Usage of Materials (ES2)**			**10.40**
4.1	In Terms of Quantity (ES2a)		4.60	
a)	*Minimizing Timber Usage by Reducing the Need for Timber*	0.20		
b)	*Minimizing Timber Usage by Re-using to Minimize New Extraction*	0.80		
c)	*Minimizing Water Usage*	0.40		
d)	*Minimizing Aggregate Usage by Reducing the Need for Aggregate*	0.80		
e)	*Minimizing Aggregate Usage by Re-using to Minimize New Extraction*	1.40		
f)	*Minimizing Usage of Other Materials*	1.00		
4.2	In Terms of Impacts during Extraction (ES2b)		6.00	
a)	*Extracting Timber from Sustainable Sources*	1.80		
b)	*Extracting Aggregates from Sustainable Sources*	4.20		
5	**Investment in Natural Capital (ES5)**			**10.20**
5.1	To Maintain Natural Capital Stock (ES5a)		5.80	
a)	*Clearing Away Sand, Mud and Waste Periodically*	4.50		

b)	*Taking Measures to Avoid Spreading Invasive Species*	1.30		
5.2	To Enhance Natural Capital Stock (ES5b)		4.30	
a)	*Plantation around the Project Area and Upper Catchment*	1.80		
b)	*Preserving Species (flora and fauna, both terrestrial and aquatic)*	2.50		
6	**Minimizing Land Use Issues (ES1)**			**9.20**
6.1	Minimizing Land Use in terms of Land Area (ES1a)		3.5	
a)	*Minimizing Submerged Area*	1.50		
b)	*Minimizing Land Use for Permanent Structures*	1.50		
c)	*Designing Temporary Facilities that can be Incorporated into Permanent Works*	0.25		
d)	*Improving and Using Existing Facilities to Minimize New Temporary Facilities*	0.30		
6.2	Minimizing Damages to Land Composition (ES1b)		5.6	
a)	*Avoiding Selection of Ecologically Valuable Sites*	2.60		
b)	*Avoiding Soil Erosion*	0.90		
c)	*Minimizing Rock Blasting*	0.60		
d)	*Minimizing Excavation*	1.40		
7	**Compliance with Environmental Laws and Standards (ES8)**			**7.90**
a)	*Compliance with Environmental Standards*	5.30		
b)	*Preventing Animal Poaching*	0.80		
c)	*Preventing Illegal Logging*	1.90		
8	**Contributions to Eradicate Poverty (ES7)**			**7.50**
a)	*Providing Employment Opportunities*	2.90		
b)	*Community Services*	4.60		
TOTAL				**100.00**

The conceptual framework provides the basis for developing ERSs for Sri Lankan infrastructure projects. In the application of the conceptual framework to the SHP sector, it was realized that some sub-factors under ES factors are not relevant to the Sri Lankan SHP projects, which necessitated a redistribution of the weighting of the main factor among the remaining sub-factors accordingly.

10.5. Summary

The chapter compared the proposed conceptual framework with existing infrastructure-related ERSs and the GBCSL system in Sri Lanka. The study is premised upon the view that the natural environment should be sustained for everything else to be sustained. Thus, the proposed conceptual framework showed more attention to ecology, biodiversity and natural capital in comparison with other ERSs. It also considers socio-economic factors which are barriers to environmental sustainability in developing countries. It is significant that the proposed basis for ERSs shares almost similar regional priorities with the GBCSL system despite the differences in the two sectors, buildings and infrastructure. The chapter also discussed the key results of the survey, together with the interview findings and the literature review, which supplemented the results.

Chapter 11: Conclusion

11.1. Introduction

The chapter revisits the objectives of the study and discusses the degree to which they were achieved in the study. The chapter then discusses the implications of the study, both from a theoretical perspective and from the point of view of practice. It then presents the limitations and recommendations including possible directions for future research and concluding remarks.

11.2. Revisiting the Objectives

1. The first objective was to "identify the theoretical underpinnings of environmental sustainability in infrastructure development as the basis for assessing infrastructure projects".

The literature review on the theories underlying the concept of sustainable development emphasized the role of the natural environment as that which sustains all other phenomena and activities. Since construction activities are part of the economic system, as indicated by Graham (2003), knowledge on the interdependencies between constructed items and the natural environment is necessary in order to make decisions on environmental sustainability. ERSs are developed to assess the environmental performance of constructed items and the basis for ERSs should identify the impacts of constructed items on the natural environment. Any negative impacts should be controlled and minimized while positive impacts should be enhanced. Therefore the study reviewed available literature in order to identify the interactions between the natural environment and the economic system and to determine the major uses of and impacts on the natural environment of economic activities, with special reference to infrastructure development. The major factors and sub-factors were summarized based on a review of each factor, which included ecological aspects that should be assessed by ERSs.

The literature on ERSs showed that there are criticisms on existing ERSs for their lack of attention to economic and social factors. However, there is a trend to include them in ERSs. But the current study subscribes to the view that the sustenance of the natural environment takes precedence over all else since the sustainability of everything else depends on the natural environment and that, therefore, impacts on the natural environment should be the focus of ERSs. In developing countries, socio-economic factors tend to receive priority in government agendas due to public pressure and political interests even at the expense of environmental impacts. Thus ERSs can play an important role in ensuring environmental sustainability rather than including socio-economic factors which would make the assessment conflicting and unnecessarily complicated. However, there are socio-economic barriers to environmental sustainability in developing countries. Hence, such factors were reviewed and considered in the study. Likewise, the interactions between the natural environment and the economic system were identified and the basis for environmental sustainability in infrastructure development was established, thus achieving the first objective.

2. The second objective was "to propose a conceptual framework for developing ERSs in the Sri Lankan infrastructure sector".

The hypothesized factors were evaluated in the survey and the interviews to identify their importance and relevance when it comes to assessing the environmental sustainability of Sri Lankan infrastructure projects. Based on the results, the conceptual framework for developing ERSs in Sri Lankan infrastructure projects was developed, thus achieving the second objective.

3. The third objective was "to apply the proposed conceptual framework to a specific infrastructure project type in Sri Lanka in order to demonstrate how to develop theoretically sound type-specific ERSs".

The conceptual framework was applied to the SHP sector in Sri Lanka. It identified and validated both the negative and positive environmental impacts of SHP projects throughout their life cycle under each ES factor in the conceptual framework while evaluating simultaneously their importance or severity. The conceptual framework was validated and the study demonstrated the application of the proposed conceptual framework for ERSs to a specific type of infrastructure. This enabled the study to achieve the third objective and the overall aim of the study.

11.3. Implications

11.3.1. Contributions to Practice

Although there are a number of ERSs for assessing buildings, there is still no agreed theoretical basis for ERSs. The number of ERSs available to assess infrastructure projects, compared to those for buildings, is lower although the matter has been receiving some attention in developed countries in the recent past and some ERSs for assessing infrastructure projects have been published in those countries. The present study addressed a critical gap in the field by proposing a conceptual framework for ERSs in the infrastructure sector in developing countries.

The study contributed to practice by transforming concepts of Environmental Economics and the broad objectives of sustainable development into project-level actions. It identified the major environmental impacts of infrastructure projects based on the theoretical underpinnings provided by the concept of sustainability and showed how these impacts need to be addressed in order to ensure the environmental sustainability of infrastructure projects. Hence, the present study creates a link between theory and practice in the sustainability paradigm via the field of environmental assessment. The proposed framework is particularly useful for developing ERSs in the Sri Lankan infrastructure sector in terms of criteria selection as well as in assigning weightings since it identified the current regional priorities with regard to environmental aspects requiring most attention in the sector.

Chapter 3 identified the criticisms of existing ERSs and underscored the fact that establishing a conceptual framework for ERSs would contribute towards overcoming these shortcomings in the field of ERSs to some extent. Hence, the study contributed to practice, by addressing the prevailing shortcomings in the field of ERSs, and by providing several approaches in the development of new ERSs to overcome deficiencies in current practice as follows.

1) As indicated in Sections 1.2 and 3.6.8, ERSs originated in developed countries which are not originally designed to accommodate national or regional variations are either directly applied in other regions or used to develop new ERSs with some adjustments to acknowledge regional variations. However, Section 3.6.8 also showed that either direct application or the configuration of these ERSs for application to another regime is a difficult proposition and is recognized as problematic. Also due to the absence of a theoretical basis to develop new ERSs, these ERSs are not theoretically sound. This study proposed a theoretical basis for developing new ERSs and demonstrated how to develop theoretically sound regional-specific ERSs.

2) The study not only provided a conceptual framework for developing type-specific ERSs in infrastructure sector but also showed a systematic approach to develop type-specific ERSs starting with field survey and public participation to identify the real environmental impacts of different types of projects, and through a data redundancy point to develop comprehensive ERSs for different types of projects. This approach employed a pair wise comparison of factors to assign meaningful weightings as a means to overcome the deficiencies in ERSs due to the absence of absolute measures up to a certain extent, by providing ratio-scale measurements which can be attributed to a single unit for meaningful comparisons as explained in Section 7.8.1.

The application of the conceptual framework to the SHP sector identified both the environmental problems as well as the positive impacts of a widespread project type in Sri Lanka. With the SHP sector gaining in popularity in Sri Lanka, it is helpful for those in the SHP sector to assess its environmental impacts and to work towards sustainability while contributing to the national electricity supply.

11.3.2. Contribution to Knowledge

Section 3.7.3 highlighted an emerging trend to take into consideration a wide range of sustainability aspects in ERSs in construction, but showed that there is no agreement on what aspects to be used or which view of sustainability to be followed. The study made a theoretical contribution by emphasising the view that the natural environment should be sustained for everything else to be sustained and the focus of ERSs should be the environmental performance of projects thus raising a voice on behalf of the natural environment. Survey results show that factors directly related to environmental performance received higher ranking compared to socio-economic aspects.

The study also made a theoretical contribution to the domain of environmental sustainability in infrastructure projects. It proposed a theoretical basis for the environmental sustainability of infrastructure development in developing countries. The study established the requirements to achieve environmental sustainability in infrastructure projects in developing countries through the theoretical underpinnings offered by the discourse and hence interpreted the underlying concepts of environmental sustainability based on the concepts of Environmental Economics and highlighted the linkages between the natural environment and the economic system.

Also the interviews supplemented the fact that the concept of sustainable development and its theoretical underpinnings are varied according to the region where there are different requirements in the developing region and even within countries. The study identified the interactions between the natural environment and the economic system as the basis for environmental sustainability. However, in the case of developing countries, there are socio-economic barriers too to environmental sustainability. Another barrier to environmental sustainability is non-compliance with laws and environmental standards. Therefore, the study suggested that when addressing environmental sustainability in developing countries, socio-economic barriers too should be addressed in addition to ecological factors. The study thus contributes to theory by defining the basis for environmental sustainability in developing countries.

As shown in Section 6.3.3, to attain equilibrium between natural environment and economic system in terms of two types of flows: source and sink, the economic system has to compensate what it harnesses from the natural environment by injecting a part of its output into it. In this vein, theoretical arguments of Environmental Economists emphasised the importance of investing in natural capital. The present study provided the supporting evidence for these arguments by showing ways to apply them at the project level. Also the study highlighted that not only the equilibrium in terms of investment but also the quality of natural environment must be considered in terms of its diversity. The factor “Conserving Biodiversity” (ES6) received the highest weighting in the conceptual framework.

11.4. Limitations

As shown in Chapter 3, due to the absence of absolute measures, ERSs still depend on expert opinion when assessing environmental sustainability. The present study thus resorted to the survey research design. The study used a combination of purposive and snowball sampling in order to locate as many experts as possible working in this field for the study.

The conceptual framework was applied to the SHP sector in Sri Lanka, a sector that is of recent origin, which contributes to the county’s national power requirements. However, the sector is not without its environmental issues. Moreover, the number of experts engaged in the SHP sector in Sri Lanka is limited. Similarly, in the approving agencies, two to three experts handle hundreds of projects. Therefore, data collection relating to the SHP sector was limited to a few experts, which made it difficult to employ some of the rigorous statistical data analysis techniques considering the small sample size. The study therefore used the AHP technique which does not rely on sample size but on representativeness.

11.5. Recommendations

The study demonstrated the application of the proposed conceptual framework for ERSs for assessing infrastructure projects in Sri Lanka by applying it to the SHP sector in Sri Lanka. The weightings of ES factors in the conceptual framework reflected the regional priorities with regard to environmental issues in infrastructure development. The study showed that when applying the framework to a specific infrastructure project type, the environmental issues of the particular project type should be identified first. Stakeholder and public participation too is important at this stage in order to identify all the issues. This is helpful in maintaining the comprehensiveness of ERSs.

It is also recommended to identify the issues in all the stages of the project life-cycle, starting with site selection, construction and operation to project phase-out if any. This is helpful in terms of life-cycle coverage as well as in terms of the comprehensiveness of ERSs.

11.6. Future Research

Political leaders, administrators, practitioners and researchers are now beginning to take serious note of the dearth of infrastructure-related ERSs. Since ERSs are mostly market-based mechanisms, more theoretical contributions to the field will be helpful in improving current practice in the domain of ERSs. The Chapter 3 showed that there is no agreed theoretical framework for criteria selection and for assigning weightings in the development of ERSs. This study provided a conceptual framework to address this gap but due to the absence of absolute measures as explained in Section 3.6.7, the study had to depend on expert opinion to find the relative importance of factors in the conceptual framework. However, to make the weightings in ERSs rigorous, it is useful to reveal the global carrying capacities in terms of a single unit, such as natural capital valuation which is already underway but requires further researches extensively.

As also pointed out in the validation exercise, though factors proposed in the conceptual framework are relevant and important in achieving environmental sustainability in the Sri Lankan infrastructure projects, further research is needed to explore ways to effectively evaluate these factors more effectively in ERSs. In this vein, effective indicators should be determined to each factor identified in the conceptual framework. The Section 8.7 showed that although compliance with environmental laws and standards is important to ensure environmental sustainability of construction projects, there are difficulties in measurement. Hence, further research is required to employ appropriate indicators to make the assessment effective.

Performing sensitivity analysis is useful to test the stability of priority ranking in AHP results. It is critical when using AHP for selecting alternatives at the bottom most level in a hierarchical structure or to select one or a certain number of elements in an intermediate level. However this study used AHP to assign weightings for a set of factors. In future, when researches are applying the proposed framework to different types of projects, sensitivity analysis can be performed to compare the sensitivity of the weightings of the main factors and sub-factors, across different project types.

11.7. Conclusion

The study aimed at providing a theoretical basis for ERSs for assessing infrastructure projects in Sri Lanka. In the process, it developed a conceptual framework which included factors assessing the environmental sustainability of infrastructure projects and their relative importance based on regional priorities. The theoretical underpinnings of the concept of “sustainability” were reviewed with the understanding that the natural environment should be sustained above all else to ensure the sustainability of other life-forms and phenomena. It is therefore necessary that the interactions between the natural environment and the economic system be properly addressed to achieve sustainability. Construction and infrastructure development constitute major components of the economic system and economic activities. Therefore, the conceptual framework was developed based on the interactions between the natural environment and economic system, which was identified through a review of the concepts of Environmental Economics.

However, in developing countries, certain socio-economic issues are barriers to environmental sustainability. In fact, it is common in some instances for economic issues to be given priority at the expense of environmental aspects and problems. Corruption in environmental related activities also exacerbates environmental destruction in some countries. Although social and economic issues are usually considered under the widely known triple bottom line of sustainability, in this study, the factors ES7 (eradicating poverty) and ES8 (compliance with environmental standards) were considered as barriers to environmental sustainability in developing countries. Therefore the contributions to minimize these issues in the developing countries would be beneficial as this would reduce the pressure on the environment, and indirectly contribute to environmental sustainability. Such efforts can be acknowledged in ERSs. Therefore, contributions to eradicate poverty at the project level and avoiding corruption were considered in the conceptual framework proposed in the study.

The set of identified factors were analysed for their relative importance when it comes to assessing the environmental sustainability of infrastructure projects. A cross-sectional survey was carried out among experts in the field in Sri Lanka and the data were analysed using the AHP method. Interviews were carried out with several experts to supplement the survey results and for in-depth understanding of the relative importance of the factors to a study of environmental sustainability in infrastructure projects. The results showed that conserving biodiversity, waste issues and usage of non-renewable energy sources were the most important environmental issues requiring priority attention when assessing Sri Lankan infrastructure projects. Other ecological factors, namely, usage of materials, investing in natural capital and land use received high weightings. Two socio-economic issues, namely, contributions to eradicate poverty and avoiding corruption ranked last in terms of importance. Interviews revealed that problems such as illegal activities by the project team members that create adverse environmental impacts and non-compliance with environmental laws and standards are not always involve corruption but lack of monitoring and misbehaviour by the project team members are also causes. Therefore, embracing these aspects, compliance with environmental laws and standards is considered in the conceptual framework.

Considering the survey results and interview findings, the conceptual framework was proposed including factors and their relative importance in terms of weightings. The proposed conceptual framework was validated using expert reviews and it is then applied in the SHP sector in Sri Lanka in order to demonstrate its application in developing type-specific ERSs. The field survey and interviews were carried out to identify the environmental impacts throughout the lifecycle of SHP projects under each main factor in the conceptual framework. Using expert opinion, solutions to the identified environmental problems, and positive impacts were arranged in a hierarchical structure with the relative importance of each factor analysed using the AHP method. Application of the proposed framework to the SHP sector showed examples from the SHP sector for incorporating factors in the proposed framework at the project level.

The conceptual framework was compared with existing environmental assessment methods. A comparison with existing infrastructure ERSs showed that the conceptual framework of the present study demonstrated more concern for ecology and biodiversity and emphasized the need for investment in natural capital. This reflects the theoretical underpinnings of environmental sustainability based on the interactions between the natural environment and the economic system. Unlike the majority of previous ERSs, the conceptual framework of the present study is proposed for the developing region, thus taking into consideration socioeconomic barriers to environmental sustainability as well. This approach encourages and enables project stakeholders to perform in such a way as to minimize barriers to environmental sustainability when prioritizing environmental performance. The comparison with the GBCSL system highlighted similarities despite sector-specific differences, thus both highlighting and justifying the recognition of regional priorities.

The study considered the features brought to light in the literature review on ERSs: comprehensiveness, life-cycle coverage and the consideration of environmental issues in detail at different levels. The validation exercise also showed that the study has successfully applied these features to the proposed conceptual framework. The experts acknowledged that consideration of environmental issues in detail at different levels can facilitate the modification of weightings according to up-to-date regional priorities. Hence, the conceptual framework provides the basis for developing type-specific, region-specific and up-to-date ERSs for infrastructure projects.

References

Abbasi, T. and Abbasi, S.A. (2011) Small hydro and the environmental implications of its extensive utilization. *Renewable and Sustainable Energy Reviews*, 15, 2134-2143.

Abdalla, G., Maas, J., Huyghe, J. and Oostra, M. (2011) Criticism on Environmental Assessment Tools. In S. Baby and B. Zygmunt (Eds.) *Proceedings of 2nd International Conference on Environmental Science and Technology (ICEST 2011)* (pp. V2-443- V2446). Singapore: IEEE.

Abu Dhabi Urban Planning Council (2010*) Estidama.* Retrieved 16 October 2013 from the World Wide Web: http://www.estidama.org/

ADB and ADBI (2009) *Infrastructure for Seamless Asia*. Tokyo: Asian Development Bank and Asian Development Bank Institute.

ADB (2013) *Energy Outlook for Asia and the Pacific*. Philippines: Asian Development Bank.Akgunduz, A., Zetu, D., Banerjee, P. and Liang, D. (2002) Evaluation of sub-component alternatives in product design processes. *Robotics and Computer Integrated Manufacturing*, 18, 69–81.

Akinola, D. B., Eekpo, C. G. and Haruna, O. I. (2012) Poverty eradication: Panacea for environmental sustainability in Nigeria. *Continental Journal of Environmental Sciences*, 6 (3), 42 – 47.

Ali, H. H. and Al Nsairat, S. F. (2009) Developing a green building assessment tool for developing countries – Case of Jordan. *Building and Environment*, 44, 1053–1064.

Alyami, S. H. and Rezgui, Y. (2012) Sustainable building assessment tool development approach. *Sustainable Cities and Society*, 5, 52–62.

Alyami, S. H., Rezgui, Y. and Kwan, A. (2013) Developing sustainable building assessment scheme for Saudi Arabia: Delphi consultation approach. *Renewable and Sustainable Energy Reviews*, 27, 43–54.

Amarawickrama, H. A. and Hunt, L. C. (2004) *Sri Lankan Electricity Supply Industry: A Critique of Proposed Reforms (Surrey Energy Economics Discussion paper Series)*. Guildford: Department of Economics, University of Surrey.

Angkananon, K., Wald, M. and Gilbert, L. (2013) Issues in conducting expert validation and review and user evaluation of the technology enhanced interaction framework and method. In Moscholios, Ioannis and Rychly, Marek (Eds.) *The Eighth International Conference on Internet and Web Applications and Services. ICIW 2013:* IARIA, 124-128.

Armstrong, D. (2005) Causal mapping: A discussion and demonstration. In V. K. Narayanan and D. Armstrong (Eds.), *Causal mapping for research in information technology* (pp. 20-45), USA: Idea group.

Arroyo, M. T. K., Marticorena, C., Matthei, O. and Cavieres, L. (2000) Plant invasions in Chile: Present patterns and future predictions. In H A. Mooney and R . J. Hobbs (Eds.), *Invasive species in a changing world* (pp. 385-41), Washington, D. C.: Island Press.

Asafu-Adjaye, J. (2005) *Environmental economics for non-economists: Techniques and Policies for Sustainable Development* (2nd ed.). Singapore: World Scientific Publishing Co. Pte. Ltd.

Asia Green Buildings (2013) *Philippines Rewards Industry for Complying with Nations Voluntary Green Rating System (BERDE).* Retrieved 14 November 2013 from the World Wide Web: http://www.asiagreenbuildings.com/doe-recognizes-industry-for-berde-building-projects-in-the-philippines/.

Bakis, R. (2007) The Current Status and Future Opportunities of Hydroelectricity. *Energy Sources, Part B: Economics, Planning, and Policy*, 2 (3), 259-266.

Banani, R. A. (2011) *A sustainable assessment method for non-residential buildings in Saudi Arabia: Development of Criteria*. Unpublished Doctoral Transfer Report, University of Reading.

Barraclough, S. L. (2001) *Toward Integrated and Sustainable Development?*. Geneva: United Nations Research Institute for Social Development.

BCA (2009) *BCA Green Mark for Infrastructure Version 1.0.* Singapore: Building and Construction Authority.

BCA (2012) *Singapore celebrates 1,000th BCA Green Mark Building Project, News Release.* Retrieved: 28 December 2013 from the World Wide Web: http://www.bca.gov.sg/Newsroom/pr26022012_GM.html.

BEAM Society (2013) *Building Environmental Assessment Method, Hong-Kong.* Retrieved: 12 December 2013 from the World Wide Web: http://www.beamsociety.org.hk/en_beam_assessment_project_1.php.

Berg, B. L. (2007) *Qualitative research methods for the social sciences*. Boston; Pearson.

Bhattacharya, A., Romani, M. and Stern, N. (2012) *Infrastructure for development : meeting the challenge*. London: Centre for Climate Change Economics and Policy and Grantham Research Institute on Climate Change and the Environment.

Biller, D. and Nabi, I. (2013) *Investing in Infrastructure: Harnessing its Potential for Growth in Sri Lanka.* Washington, D.C.: The World Bank.

BOI (2013) *Key Sectors For Investment – Infrastructure*. Board of Investment, Sri Lanka. Retrieved: 22 July 2013 from the World Wide Web: http://www.investsrilanka.com/.

Boulding, K. (1966) ‘The Economics of the Coming Spaceship Earth’. In H. Jarrett (Ed.), *Environmental Quality in a Growing Economy* (pp. 3-14). Baltimore: Johns Hopkins University Press.

Brandon, P. S. and Lombardi, P. (2011) *Evaluating sustainable development in the built environment* (2nd ed). Oxford: John Wiley and Sons, Ltd.

BRE (2013) *BREEAM*. Retrieved: 19 October 2013 from the World Wide Web: http://www.breeam.org/.

BRE (2013) *Who specifies BREEAM*. Building Research Establishment. Retrieved: 19 October 2013 from the World Wide Web: http://www.breeam.org/podpage.jsp?id=273.

Bryman, A. and Bell, E. (2003) *Business Research Methods*. Oxford: Oxford University Press.

Budhathoki, S. (2011) *Grid Connection of Gotikhel Micro Hydropower Plant Without Interrupting Isolated Load*. Norderstedt: GRIN Verlag.

Carmone, F. J. Jr., Ali Kara, Zanakis, S.H. (1997) A Monte Carlo investigation of incomplete pairwise comparison matrices in AHP. *European Journal of Operational Research*, 102 (3), 538–553.

Cavendish, W. (2000) Empirical regularities in the poverty-environment relationship of rural households: Evidence from Zimbabwe. *World Development*, 28 (11), 1979-2003.

CEA (2013) *Environmental Impact Assessment (EIA) Procedure in Sri Lanka*. Retrieved: 19 October 2013 from the World Wide Web: http://www.cea.lk/index.php/ta/environmental-impact-assessment-eia-procedure-in-sri-lanka.

CEB (2001) *Statistical Digest- 2001*. Sri Lanka: Ceylon Electricity Board.

CEB (2002) *Statistical Digest- 2002*. Sri Lanka: Ceylon Electricity Board.

CEB (2003) *Statistical Digest- 2003*. Sri Lanka: Ceylon Electricity Board.

CEB (2004) *Statistical Digest- 2004*. Sri Lanka: Ceylon Electricity Board.

CEB (2005) *Statistical Digest- 2005*. Sri Lanka: Ceylon Electricity Board.

CEB (2006) *Statistical Digest- 2006*. Sri Lanka: Ceylon Electricity Board.

CEB (2007) *Statistical Digest- 2007*. Sri Lanka: Ceylon Electricity Board.

CEB (2008) *Statistical Digest- 2008*. Sri Lanka: Ceylon Electricity Board.

CEB (2009) *Statistical Digest- 2009*. Sri Lanka: Ceylon Electricity Board.

CEB (2010) *Statistical Digest- 2010*. Sri Lanka: Ceylon Electricity Board.

CEB (2011) *Ceylon Electricity Board*. Retrieved: 11 November 2011 from the World Wide Web: http://www.ceb.lk.

CEB (2012) *Statistical Digest- 2012*. Sri Lanka: Ceylon Electricity Board.

CEB (2013) *Opportunities for Renewable Energy Development*. Retrieved: 11 November 2011 from the World Wide Web: http://www.ceb.lk/sub/db/op_presentstatus.html.

CEEQUAL (2010) *Assessment Manual for Projects in the UK and Ireland: Version 4.1*. United Kingdom: CEEQUAL Ltd.

CEEQUAL (2011) *CEEQUAL*. Retrieved: 25 April 2011 from the World Wide Web: http://www.ceequal.com.

Central Bank (2012) *Annual report.* Sri Lanka: Central Bank of Sri Lanka.

Chatterton, P. and Style, S. (2001) Putting Sustainable Development into Practice? The role of local policy partnership networks. *Local Environment*, 6 (4), 439–452.

Ciegis, R. and Ciegis, R. (2008) Laws of thermodynamics and sustainability of the economy. *Engineering Economics*. 57 (2), 15-22.

Cole, R. (1998) Emerging trends in building environmental assessment methods. *Building Research and Information*, 26 (1), 3-16.

Cole, R. J. (1999) Building environmental assessment methods: clarifying intentions. *Building Research and Information*, 27(4/5), 230-246.

Cole, R. J. (2003) Building Environmental Assessment Methods: A Measure of Success. International Electronic Journal of Construction, Special Issue, *The Future of Sustainable Construction*.

Cole, R. J. (2005) Building environmental assessment methods: redefining intentions and roles. *Building Research and Information*, 35 (5), 455-467.

Cole, R. J. (2006) Shared markets: coexisting building environmental assessment methods. *Building Research and Information*, 34 (4), 357-371.

Cole, R. J., Howard, N., Ikaga, T. and Nibel, S. (2005) *Building Environmental Assessment Tools: current and future roles*. Paper presented at *World Sustainable Building Conference*, Tokyo, Japan, 27-29 September.

Cole, R. J. and Valdebenito, M. J. (2013) The importation of building environmental certification systems: international usages of BREEAM and LEED.
Building Research and Information, 41 (6), 662–676.

Common, M. S. and Stagl, S. (2005) *Ecological economics: an introduction.* New York: Cambridge University Press.

Commonwealth of Australia (2010) *NatHERS - Nationwide House Energy Rating Scheme*. Retrieved: 16 October 2013, from the World Wide Web: http://www.nathers.gov.au/index.php.

Cooper, I. (1999) Which focus for building assessment methods-Environmental performance or sustainability?. *Building Research and Information*, 27 (4/5), 321-331.

Crawley, D. and Aho, I. (1999) Building environmental assessment methods: applications and development trends. *Building Research and Information*, 27(4/5), 300–308.

Curwell, S., Deakin, M. and Symes, M. (2005) *Sustainable urban development Volume 1: The framework and protocols for environmental assessment*. New York: Routledge.

Daly, H. E. and Cobb, J.B. (1989) *For the Common Good: Redirecting the Economy Toward Community, the Environment and Sustainable Future*. Boston : Beacon Press.

Daly, H.E. (1992) Is the Entropy Law Relevant to the Economics of Natural Resource Scarcity?-Yes, of Course It Is!. *Journal of Environmental Economics and Management*, 23, 91-95.

Daly, H.E. (1994) Operationalizing sustainable development by investing in natural capital. In A. Jansson, M. Hammer, C. Folke and R. Costanza (Eds.), *Investing in Natural Capital: the ecological economics approach to sustainability*. Washington, DC: Island Press.

Daly, H. E. and Farley, J. (2004) *Ecological Economics: Principles and Applications*. Washington, D.C.: Island Press.

Dasgupta, S. and Tam, E. (2005) Indicators and framework for assessing sustainable infrastructure. *Canadian Journal of Civil Engineering*, 32(1), 30-44.

Deakin, M., Mitchell, G., Nijkamp, P. and Vreeker, R. (2007) *Sustainable urban development Volume 2: The environmental assessment methods*. New York: Routledge.

DeForge, B. R. (2010) Research Design Principles (pp.). In N. J. Salkind (Ed.), *Encyclopaedia of Research Design*. London: Sage publications.

de Groot, R. S. (1992) *Functions of nature: evaluation of nature in environmental planning, management and decision making*. Wolters - Noordhoff.

de Groot, R. S. (1994) Environmental functions and the economic value of natural ecosystems (pp.). In A. Jansson, M. Hammer, C. Folke, and R. Costanza (Eds.), *Investing in Natural Capital: the ecological economics approach to sustainability.* Washington, D.C.: Island Press.

Department of Meteorology (2013) *Climate in Sri Lanka*. Retrieved: 16 October 2013, from the World Wide Web: http://www.meteo.gov.lk/index.php?option=com_content&view=article&id=106&Itemid=81&lang=en.

Department of National Planning (2010) *Sri Lanka - The Emerging Wonder of Asia: Mahinda Chintana Vision for the Future*. Retrieved: 02 December 2011, from the World Wide Web: http://www.treasury.gov.lk/EPPRM/npd/pdfdocs/mahindaChintan-vision-2010/ENGLISH/mahindaChintanaVision-2010full-eng.pdf.

DFCC (2007) *Private Sector, Small-scale, Grid-connected Renewable Power Generation in Sri Lanka: A review of the experience of the past decade 1996 to 2006*. Sri Lanka: DFCC Consulting (Private) Limited.

DGNB (2013) *DGNB System*. Retrieved: 13 October 2013, from the World Wide Web: http://www.dgnb-system.de/en/contact/.

Ding, G. K. C. (2004) *The development of a multi-criteria approach for the measurement of sustainable performance for built projects and facilities*, MSc thesis, University of Technology, Sydney.

Ding, G. K. C. (2008) Sustainable construction-The role of environmental assessment tools. *Journal of Environmental Management*, 86, 451-464.

Drexhage, J. and Deborah, M. (2010) *Sustainable Development: From Brundtland to Rio 2012*. New York: United Nations.

Dwivedi, D. N. (2010) *Macroeconomics: Theory and Policy*. New Delhi: Tata McGraw-Hill Education.

ECG (2007) *The Nexus Between Infrastructure and Environment from the Evaluation Cooperation Group of the International Financial Institutions*. Washington, D. C.: The World Bank.

Eddy, D. M., Hollingworth, W., Caro, J. J., Tsevat, J., McDonald, K. M. and Wong, J. B. (2012) Model Transparency and Validation: A Report of the ISPOR-SMDM Modelling Good Research Practices Task Force-7. *Value in Health*, 15 (6), 843–850.

El-Adaway, I. and Knapp, J. (2012) Towards a More Sustainable Rating for the Built Environment: A Comprehensive Construction Assessment Framework. In H. Cai, A. Kandil, M. Hastak and P. S. Dunston (Eds.)

Proceedings of Construction Research Congress (pp. 1981- 1990). Reston: American Society of Civil Engineers.

ESCI (2012) *Korea Green Building Certification*. Retrieved 19 October 2013 from the World Wide Web: http://esci-ksp.org/?project=korea-green-building-certification-kgbc.

Evans, M., Shui, B. and Takagi, T. (2009) *Country Report on Building Energy Codes in Japan*. US Department of Energy. Retrieved 17 October 2013 from the World Wide Web: http://www.energycodes.gov/country-reports-building-energy-codes.

FAO (1997) *Land quality indicators and their use in sustainable agriculture and rural development (Land and Water Bulletin 5).* Rome: FAO.

Fenner, R. A. and Ryce, T. (2008) A comparative analysis of two building rating systems. Part 1: Evaluation. *Engineering Sustainability*, 161, 55-63.

Ferdinando, M. M. C. and Gunawardana, R.J. (2011) Electricity Generation from Renewable Energy in Sri Lanka: Future Directions. Paper presented at the *5th "Hydropower for Today Forum" of International Centre on Small Hydro Power*, Hangzhou, China.

Flombaum, P. and Sala, O. E. (2008) Higher effect of plant species diversity on productivity in natural than artificial ecosystems. *Proceedings of National Academy Sciences of the United States of America*, 105(16): 6087–6090.

Forest department (2013) Forest resources. Forest department of Sri Lanka. Retrieved 16 October 2013from the World Wide Web: http://www.forestdept.gov.lk/web/index.php?option=com_content&view=article&id=112&Itemid=131&lang=en

Forsberg, A. and von Malmborg, F. (2004) Tools for environmental assessment of the built environment. *Building and Environment*, 39, 223 – 228.

Gardner, J. E. (1989) Decision making for sustainable development: selected approaches to environmental assessment and management. *Environmental Impact Assessment Review*, 9, 337-366.

GBCA (2013) *Green Star, Green Building Council Australia*. Retrieved 16 October 2013 from the World Wide Web: http://www.gbca.org.au/.

GBCSL (2011) *Green Rating System for Built Environment: Version 1.0*. Sri Lanka: Green Building Council Sri Lanka.

Gibberd, J. (2001) The Sustainable Building Assessment Tool: Assessing how buildings can support sustainability in Developing Countries. Paper presented at *the Built Environment Professions Convention, IFI International Conference*, Johannesburg, South Africa.

Giddings, B., Hopwood, B. and O'Brien, G. (2002) Environment, economy and society: fitting them together into sustainable development. *Sustainable Development*, 10, 187–196.

Glavinich, T. E. (2008) *Contractor's Guide to Green Building Construction: Management, Project Delivery, Documentation, and Risk Reduction*. New Jersey: John Wiley and Sons, Inc.

Goepel, K. D. (2013). Implementing the Analytic Hierarchy Process as a Standard Method for Multi-Criteria Decision Making In Corporate Enterprises – A New AHP Excel Template with Multiple Inputs, *Proceedings of the International Symposium on the Analytic Hierarchy Process*.

Goodland, R. and Daly, H. (1993) Poverty alleviation – A must for Environmental Sustainability. *Sustainable Development*, 1(3), 8-22.

GOSL (2013) Sri Lanka at a glance, Government of Sri Lanka. Retrieved 16 October 2013from the World Wide Web: http://www.gov.lk/web/index.php?option=com_content&view=article&id=226&Itemid=289&lang=en.

Graham, P. (2003) *Building Ecology: First Principles for a Sustainable Built Environment*. Oxford: Blackwell Science.

Green Building Index (2013) *Green Building Index*. Retrieved 19 October 2013 from the World Wide Web: http://www.greenbuildingindex.org/.

Green Globes (2013) *The Practical Building Rating System*. Retrieved 19 October 2013 from the World Wide Web: http://www.greenglobes.com/.

GRIHA (2013) Green Rating for Integrated Habitat Assessment. Retrieved 19 October 2013 from the World Wide Web: http://www.grihaindia.org/#&compendium

GSA (2013) *LEED Building Information.* Retrieved 19 October 2013 from the World Wide Web:http://www.gsa.gov/portal/category/25999.

Gu, Z., Wennersten, R. and Assefa, G. (2006) Analysis of the most widely used Building Environmental Assessment methods. *Environmental Sciences*, 3 (3), 175-192.

Haapio, A. and Viitaniemi, P. (2008) A critical review of building environmental assessment tools. *Environmental Impact Assessment Review*, 28, 469–482.

Halla, R. S., Christopher A. K. and Barry J. A. (2005) Developing sustainability criteria for urban infrastructure systems. *Canadian Journal of Civil Engineering*, 32, 72–85.

Hanley, N., Shogren, J. F. and White, B. (2001) *Introduction to environmental economics.* New York: Oxford University Press.

Harker, P. T. (1987) Incomplete pairwise comparisons in the Analytic Hierarchy Process. *Mathematical Modelling*, 9(11), 837-848.

Hendriks, C. F. (2001) *Sustainable Construction*. Boxtel: Aeneas publishers.

Hennig, T., Wang, W., Feng, Y., Ou, X. and He, D. (2013) Review of Yunnan's hydropower development. Comparing small and large hydropower projects regarding their environmental implications and socio-economic consequences. *Renewable and Sustainable Energy Reviews*, 27 (C), 585-595.

Hooper, D. U., Chapin, F. S., III, Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J. H., Lodge, D. M., Loreau, M., Naeem, S., Schmid, B., Setälä, B. Symstad, A. J., Vandermeer, J. and Wardle, D. A. (2005) Effects of Biodiversity on Ecosystem Functioning: A Consensus of Current Knowledge. *Ecological Monographs*, 75 (1), 3-35.

ICLEI (1996) *The Local Agenda 21 Planning Guide: an Introduction to Sustainable Development Planning*. Toronto: ICLEI.

IEA (2002) *Environmental and health impacts of electricity generation: A Comparison of the Environmental Impacts of Hydropower with those of Other Generation Technologies*. The International Energy Agency.

IEA (2004) *Directory of Tools: A Survey of LCA Tools, Assessment Frameworks, Rating Systems, Technical Guidelines, Catalogues, Checklists and Certificates, Annex 31*. Canada: The International Energy Agency.

IISBE (2013) *International Initiative for a Sustainable Built Environment, Canada*. Retrieved 04 December 2013 from the World Wide Web: http://www.iisbe.org/taxonomy/term/71.

IISD (2013) *What is Sustainable Development?. International Institute for Sustainable Development.* Retrieved 24 October 2013 from the World Wide Web: http://www.iisd.org/sd/.

ISCA (2013) *IS Rating Tool*, Infrastructure Sustainability Council of Australia. Retrieved 16 October 2013 from the World Wide Web: http://www.isca.org.au/.

Ishizaka, A. and Labib, A. (2011) Review of the main developments in the Analytic Hierarchy Process. *Expert Systems with Applications*, 38(11), 14336-14345.

ISI (2012) *Envision version 2.0: A rating system for sustainable infrastructure.* Washington, D. C.: Institute for Sustainable Infrastructure.

IUCN (2006) *The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century*, Report of the IUCN Renowned Thinkers Meeting, 29-31 January 2006. The World Conservation Union.

IUCN (2010) Saving biodiversity: An economic approach. *World Conservation*, 40 (1), 6-9.

Jain, T. R. and Khanna, O. P. (2007) *Economic Concepts and Methods*. New Delhi: V. K. (India) Enterprises.

Jansson, A., Hammer, M., Folke, C. and Costanza, R. (1994) *Investing in Natural Capital: the ecological economics approach to sustainability*. Washington, D.C.: Island Press.

Japan GreenBuild Council (JaGBC) / Japan Sustainable Building Consortium (JSBC) (2013) *CASBEE, Comprehensive Assessment System Built Environment Efficiency*. Retrieved: 19 October 2013 from the World Wide Web: http://www.ibec.or.jp/CASBEE/english/overviewE.htm.

Jerome, F. P. (2010) *Revving up Sri Lanka's Power Sector – Sector Report, Power Industry*. Sri Lanka: RAM Ratings (Lanka) Ltd.

Kajikawa, Y., Inoue, T. and Goh, T. N. (2011) Analysis of building environment assessment frameworks and their implications for sustainability indicators. *Sustainability Science*, 6 (2), 233-246.

Kaldellis, K., Vlachou, D.S. and Korbakis, G. (2005) Techno-economic evaluation of small hydro power plants in Greece: a complete sensitivity analysis. *Energy Policy*, 33 (15), 1969–1985.

Kendrick, J. D. and Saaty, D. (2007) Use Analytic Hierarchy Process for project selection. *ASQ Six Sigma Forum Magazine*, 6(4), 22-31.

Kenline, C. (2012) *Why Leed?: The U.S. Government and Sustainable Building*. Retrieved: 23 November 2013 from the World Wide Web: http://www.ckenline.com/research.html

Kibert, C. J. (1994) *Sustainable construction: proceedings of the First International Conference of CIB TG 16, November 6-9, 1994*, Tampa, Florida, U.S.A.

Kibert, C. J. (2005) *Sustainable construction: green building design and delivery*. New Jersey: John Wiley and Sons, Inc.

Kibert, C. J. (2008) *Sustainable construction: green building design and delivery* (2nd ed.). New Jersey: John Wiley and Sons, Inc.

Kim, B. (2006) *Infrastructure Development for the Economic Development in Developing Countries: Lessons from Korea and Japan*. GSICS Working Paper Series, No. 11, Graduate School of International Cooperation Studies, Kobe University.

Kim, H. S., and Kim, Y. G. (2009) A CRM performance measurement framework: Its development process and application. *Industrial Marketing Management*, 38 (4), 477-489.

Klostermann, J. E. M. and Cramer, J. (2006) The Contextual Meaning of Sustainable Development: The Case of the Dutch Drinking Water Sector. *Sustainable Development*, 14, 268–276.

Kodituwakku, D. C. (2004) *The Environmental Impact Assessment Process in Sri Lanka*, Sarid Journal. Retrieved: 24 November 2013 from the World Wide Web: http://sarid.net/sarid-journal/.

Krautkraemer, J. A. (2005) *Economics of natural resource scarcity: The state of the debate (Discussion paper 5 – 14)*. Washington, D.C.: Resources for the future.

Kumar, A. and Verma, H. K. (2007) Indian Initiative to Develop Standards, Guidelines and Manuals for Small Hydropower. Paper presented at the *International Conference on Small Hydropower - Hydro Sri Lanka*, Kandy, Sri Lanka.

Kumar, R. (2005) *Research methodology: A step-by-step guide for beginners.* London: Sage publications.

Langford, D. A., Zhang, X. Q., Maver, T., MacLeod, I. and Dimitrijevic, B. (1999) Design and Managing for Sustainable Buildings in the UK. In S. O. Ogunlana (Ed.) Profitable *partnering in construction procurement CIB W92 and CIB TG 23 Joint Symposium* (pp. 373-382). London: E. & F.N. Spon.

Lee, W.L., Chau, C.K., Yik, F.W.H., Burnett, J. and Tse, M.S. (2002) On the study of the credit-weighting scale in a building environmental assessment scheme. *Building and Environment*, 37 (12), 1385–1396.

Lee, W. L. (2013) A comprehensive review of metrics of building environmental assessment schemes. *Energy and Buildings*, 62, 403-413.

Lees, S. (2013) Measuring, Monitoring and Managing to Improve Sustainability - Applying the IS Rating Tool to Local Council Road Maintenance. Paper presented at *IPWEA International Public Works Conference*, Darwin, Australia, 11-15 August.

Lovins, A. B., Lovins, L. H. and Hawken (1999) *Natural Capitalism: The Next Industrial Revolution*. London: Earth scan Ltd.

Lovins, A. B., Lovins, L. H., and Hawken (2000) *A Road Map for Natural Capitalism*. In The Harvard business review paperback series, Harvard business review on business and the environment. USA: Harvard Business School Publishing.

Lyons, P. and Doueck, H.J. (2010) *The Dissertation: From Beginning to End*. Oxford University Press: New York.

Macdonald, N. T. (1999) *Macroeconomics and business: an interactive approach.* London: International Thomson Publishing.

Mamurekli, D. (2010) Environmental impacts of coal mining and coal utilization in the UK. *Acta Montanistica Slovaca*, 15 (2), 134-144.

Massaeli, A. (2011) Ranking of maximum production strategies in gas processing plant of National Iranian Gas Company using AHP. Paper presented at *the 2nd International Conference on Industrial Engineering and Operations Management*, Kuala Lumpur, Malaysia.

Mateus, R. and Braganca, L. (2011) Sustainability assessment and rating of buildings: Developing the methodology SBTool^{PT}-H. *Building and Environment*, 46, 1962-1971.

McBurney, D. H. and White, T. L. (2010) *Research methods* (8th Ed.). Belmont: Wadsworth.

Media Center for National Development of Sri Lanka (2011) *"Lak Vijaya" Power Plant at Norochcholai willl be Commissioned Tomorrow.* Retrieved: 11 November 2011 from the World Wide Web: http://www.development.lk/news.php?news=1173.

MGI (2013*) Infrastructure Productivity: How to save $1 trillion a year*. McKinsey and Company. Retrieved: 04 October 2013 from the World Wide Web: http://www.mckinsey.com/insights/engineering_construction/infrastructure_productivity.

Ministry of Environment and Renewable Energy (2013) *Ministry of Environment and Renewable Energy of Sri Lanka*. Retrieved 16 October 2013 from the World Wide Web: http://www.environmentmin.gov.lk/.

Nadar, E. N. and Vijayan, S. (2009) *Managerial Economics*. New Delhi: PHI Learning Private Limited.

Nandalal, H.K. (2007) *Importance of Public Participation in Project Implementation: Upper Kothmale Hydropower Project in Sri Lanka*. Paper presented at the International Conference on Small Hydropower, Kandy, Sri Lanka.

Narasaiah, M. L. (2005) *Biodiversity and Sustainable Development.* New Delhi: Discovery Publishing House.

NCHRP (2006) *Control of Invasive Species*. Washington DC.: National Corporative Highway Research Program.

Ndah, A. B. (2013) *Operationalizing the sustainability concept through the 'stages of sustainable development model*. Retrieved: 05 October 2013 from the World Wide Web: http://www.academia.edu.

Neumayer, E. (2003) *Weak Versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms*. Cheltenham: Edward Elgar Publishing.

Newsham, G.R., Mancini, S. and Birt, B. (2009) Do LEED-certified buildings save energy? Yes, but... *Energy and Buildings*, 41, (8), 897-905.

Newton, A.C. (2007) *Biodiversity Loss and Conservation in Fragmented Forest Landscapes: The Forests of Montane Mexico and Temperate South America*. London: CAB International.

New Zealand Green Building Council (2013) *About Green Star*. Retrieved 19 October 2013 from the World Wide Web: http://www.nzgbc.org.nz/index.php?option=com_content&view=article&id=17&Itemid=117.

OECD (2003) *Environmentally sustainable buildings: challenges and policies.* Paris: Organisation for Economic Co-Operation and Development.

OECD (2006) *Infrastructure to 2030: Telecom, Land Transport, Water and Electricity.* Paris: Organisation for Economic Co-Operation and Development.

OECD (2008) *OECD Environmental outlook to 2030.* Paris: Organisation for Economic Co-Operation and Development.

OECD (2009) *Ensuring environmental compliance: trends and good practices*. Paris: Organisation for Economic Co-Operation and Development.

OECD (2012) *Green Growth and Developing Countries: A Summary for Policy Makers.* Paris: Organisation for Economic Co-Operation and Development.

Ofori (2007) *The Project Manager and the Millennium Development Goals*. Keynote paper presented at 10th Anniversary of Project Management education at University of Moratuwa, Sri Lanka, 18 August.

O'Keefe, R.M., Balci, O. and Smith, E.P. (1987) Validation of Expert System Performance, *IEEE expert*, Winter, 81-90.

Ott, K. (2003) The Case for Strong Sustainability. In Ott, K. and P. Thapa (Eds.), *Greifswald's Environmental Ethics* (pp. 59-64), Greifswald: Steinbecker Verlag.

Paish, O. (2002) Small hydro power: technology and current status. *Renewable and Sustainable Energy Reviews*, 6, 537–556.

Palliyaguru, R.S., Amaratunga, D. and Haigh, R. (20070, Improving infrastructure to reduce future vulnerabilities to natural disasters: Review of Infrastructure Development associated with Post Tsunami Reconstruction in Sri Lanka, *Proceeding of the CIB World Congress 2007*, Cape Town, South Africa, 13-16 May.

Parker, C. and Cranford, M. (2010) *The Little Biodiversity Finance Book: A guide to proactive investment in natural capital (PINC).* Oxford: Global Canopy Foundation.

Partovi, F. Y. (1992) Determining What to Benchmark: An Analytic Hierarchy Process Approach. *International Journal of Operations and Production Management*, 14 (6), 25-39.

Paul, S. (2012) Location allocation for urban waste disposal site using multi-criteria analysis: A study on Nabadwip Municipality, West Bengal, India. *International Journal of Geomatics and Geosciences*, 3 (1), 74-88.

Pearce, D. W. and Turner, R. K. (1990) *Economics of natural resources and the environment*. Baltimore: The Johns Hopkins University Press.

Pearce, A. R., Ahn, Y.H. and HanmiGlobal (2012) *Sustainable buildings and infrastructure : paths to the future*. New York: Routledge.

PHILGBC (2013a) *Philippine Green Building Council*. Retrieved: 14 November 2013 from the World Wide Web: http://berdeonline.org/index.php/doe-peep-ebi.

PHILGBC (2013b) *BERDE, Building For Ecologically Responsive Design Excellence*, Philippine Green Building Council. Retrieved 19 October 2013 from the World Wide Web: http://berdeonline.org/.

Pinho, P., Maia, R. and Monterroso, A. (2007) The quality of Portuguese Environmental Impact Studies: The case of small hydropower projects. *Environmental Impact Assessment Review*, 27 (3), 189–205.

Poston, A., Emmanuel, R. and Thomson, C. (2010) Developing holistic frameworks for the next generation of sustainability assessment methods for the built environment. In: C. Egbu (Ed.) *Proceedings of 26th Annual ARCOM Conference* (pp. 1487-1496). Leeds: Association of Researchers in Construction Management.

Raine, A., Foster, J. and Potts, J. (2006) The new entropy law and the economic process. *Ecological Complexity*, 3, 354-360.

Razan, J. I., Islam, R. S., Hasan, R., Hasan, S., and Islam, F. (2012) A Comprehensive Study of Micro-Hydropower Plant and its Potential in Bangladesh. *ISRN Renewable Energy*. Retrieved 14 October 2013 from the World Wide Web: http://dx.doi.org/10.5402/2012/635396.

Reardon, T. and Vosti, S. A. (1995) Links between rural poverty and the environment in developing countries: Asset categories and investment poverty. *World Development*, 23 (9), 1495–1506.

Redclift, M. (2005) Sustainable development (1987-2005): An Oxymoron comes of age. *Sustainable development*, 13, 212-227.

Rees, W .E. (1999) The built environment and the ecosphere: a global perspective, *Building Research and Information*, 27 (4-5), 206-220.

Reijnders, L. and van Roekel, A. (1999) Comprehensiveness and adequacy of tools for the environmental improvement of buildings. *Journal of Cleaner Production*, 7, 221–225.

Retzlaff, R. C. (2009) Green buildings and Building Assessment Systems: A new area of interest for planners. *Journal of Planning Literature*, 24 (1), 3-21.

Robert, J. S. and Walpole, M. J. (2005). Should conservationists pay more attention to corruption?. *Oryx*, 39 (3), 251-256.

Ropke, I. (2005) Trends in the development of ecological economics from the late 1980s to the early 2000s. *Ecological Economics*, 55, 262-290.

Rupasinghe, B.W.H. A. and de Silva, S.N. (2007) Environmental Impacts of Mini Hydropower Projects in Sri Lanka. Paper presented at the *International Conference on Small Hydropower*, Kandy, Sri Lanka.

Saaty, T. L. (1994) *Fundamentals of decision making and priority theory with the analytic hierarchy process*. Pittsburgh, PA : RWS Publications.

Saaty, T. L. (2001) *Decision making for leaders: the analytic hierarchy process for decisions in a complex world* (3rd ed.). Pittsburgh, Pa.: RWS Publications.

Saaty, T. L. and Vargas, L. G. (2001) *Models, methods, concepts and applications of the Analytic Hierarchy Process.* Dordrecht: Kluwer Academic Publishers.

Saaty, T. L., and Vargas, L. G. (2006) *Decision making with the analytic network process: economic, political, social and technological applications with benefits, opportunities, costs and risks.* New York: Springer Science.

Saaty, T. L. (2008) Decision making with the Analytic Hierarchy Process. International Journal of Services Sciences, 1 (1), 83-98.

Samarakoon, M. and Rowan, J. S. (2008) A Critical Review of Environmental Impact Statements in Sri Lanka with Particular Reference to Ecological Impact Assessment. *Environmental Management*, 41, 441–460.

Sandika, A. L. and Withana, N. R. P. (2010) Economic Analysis of *Chena* Cultivation in Monaragala District, Sri Lanka. *Proceedings of the 15th International Forestry and Environment Symposium* (pp. 350-356). Sri Lanka: Department of Forestry and Environmental Science, University of Sri Jayewardenepura.

Scavarda, A. J., Chameeva, T. B., Goldstein, S. M., Hays, J. and Hill, A. V. (2004) A Review of the Causal Mapping Practice and Research Literature. Paper presented at *the Second World Conference on POM and 15th Annual POM Conference*, Cancun, Mexico.

Schweber, L. (2013) The effect of BREEAM on clients and construction professionals. *Building Research and Information*, 41(2), 129–145.

SEA (2013) *Sustainable Energy Authority Sri Lanka*. Retrieved 12 October 2013 from the World Wide Web: http://www.energy.gov.lk/sub_pgs/energy_renewable_hydro_potential.html .

Sev, A. (2011) A comparative analysis of building environmental assessment tools and suggestions for regional adaptations. *Civil engineering and environmental systems*, 28 (3), 231-245.

SGBC (2013) *Singapore Green Building Council Green Certification*. Retrieved 04 December, 2013 from the World Wide Web: http://www.sgbc.sg/.

Shah, S. (2007) *Sustainable Practice for the Facility Manager*. Oxford: Blackwell Publishing Ltd.

Shanthini, R. (2010) Could Sri Lanka afford sustainable electricity consumption practices without harming her economic growth? Paper presented at *the 9th Asia Pacific Roundtable for Sustainable Consumption and Production*, Colombo, Sri Lanka.

Sharma, S. (2011) Green Project Management Practices for Construction Industry. *International Transactions in Applied Sciences*, 3(4), 657.

Sharma, N. K., Tiwari, P. K. and Sood, Y. R. (2013) A comprehensive analysis of strategies, policies and development of hydropower in India: Special emphasis on small hydro power. *Renewable and Sustainable Energy Reviews*, 18 (C), 460-470.

Singh, J. (1995) Land degradation and economic sustainability. *Ecological Economics*, 15(1), 77-86.

Singh, S. (1999) *Ten priorities for poverty eradication*. Retrieved 31 December, 2013 from the World Wide Web: http://www.twnside.org.sg/title/ten-cn.htm.

Sinou, M. and Kyvelou, S. (2006) Present and future of building performance assessment tools false. *Management of Environmental Quality*, 17 (5), 570-586.

Siyambalapitiya, T. and Wickramasinghe, A. (2009) *Electricity (Sanvada 14) - The Electricity Act of 2009 and the Development of the Sector*. Sri Lanka: SANVADA. Retrieved 05 September, 2011 from the World Wide Web: http://sanvada.org/index.php?option=com_content&task=view&id=87&Itemid=32.

Smith, R. J., Muir, R. D. J., Walpole, M. J., Balmford, A., and Leader-Williams, N. (2003) Governance and the loss of biodiversity. *Nature*, 426(6962), 67-70.

Soebarto, V.I. and Williamson, T.J. (2001) Multi-criteria assessment of building performance: theory and implementation. *Building and Environment*, 36 (6), 681–690.

Spector, P. E. (1981) *Research designs*. London: Sage publications.

Spence, R. and Mulligan, H. (1995) Sustainable development and the construction industry. *Habitat International*, 19(3), 279-292.

Tan, W. (2008) *Practical Research Methods* (3rd ed.). Singapore: Prentice Hall.

TGBI (2011) *TREES Rating System*, Thai Green Building Institute. Retrieved 19 October, 2013 from the World Wide Web: http://www.tgbi.or.th/trees.php

Thampapillai, D. J. (2002) *Environmental Economics: Concepts, Methods and Policies*. London: Oxford University Press.

Thoradeniya, B., Ranasinghe, M., and Wijesekera, N. T. S. (2007) Social and Environmental Impacts of a Mini-hydro Project on the Ma Oya Basin in Sri Lanka. Paper presented at the *International Conference on Small Hydropower – Hydro Sri Lanka*, Kandy, Sri Lanka.

Todd, J.A. (1996) Practical approaches to LCA impact assessment. Proceedings of *89th Meeting of Air and Waste Management Association*, Nashville, Tennessee, 23- 28 June.

Todd, J. A., Crawley, D., Geissler, S. and Lindsey, G. (2001) Comparative assessment of environmental performance tools and the role of the Green Building Challenge. *Building Research and Information*, 29(5), 324–335.

Todd, J. A., Pyke, C. and Tufts, R. (2013) Implications of trends in LEED usage: rating system design and market transformation. *Building Research and Information*, 41(4), 384-400.

Townsend, K. N. (1992) Is the Entropy Law Relevant to the Economics of Natural Resource Scarcity? Comment. *Journal of Environmental Economics and Management*, 23, 96-100.

Transparency International, 2008. *Corruption and renewable natural resources*. Working paper #01-2007.

Turner, R. (1993) Sustainability: principles and practice. In R. Turner (Ed.), *Sustainable Environmental Economics and Management: principles and practice*. London: Belhaven Press.

Turner, R. K., Pearce, D. and Bateman, I. (1994) *Environmental economics: an elementary introduction*. New York: Harvester Wheatsheaf.

Ugwu, O. O. and Haupt, T. C. (2007) Key performance indicators and assessment methods for infrastructure sustainability - a South African construction industry perspective. *Building and Environment*, 42, 665-680.

UNCED (1992) Agenda 21. *United Nations Conference on Environment and Development*, Rio de Janerio, Brazil, 3 - 14 June.

UNCSD (2012) The Future We Want: Outcome document adopted at Rio+20. *United Nations Conference on Sustainable Development*, Rio de Janeiro, Brazil, 20-21 June.

UNEP (1972) Stockholm Declaration. *United Nations Conference on the Human Environment,* United Nations Environment Programme, Stockholm, Sweden, 5 - 16 June.

UNEP (2011) *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*, United Nations Environment Programme. www.unep.org/greeneconomy

UNEP (2013) *Why Buildings*. United Nations Environment Programme. Retrieved 01 February, 2013 from the World Wide Web: http://www.unep.org/sbci/AboutSBCI/Background.asp

United Nations (1992) *Convention on Biological Diversity*. Retrieved 28 December, 2013 from the World Wide Web: http://www.cbd.int/convention/text/default.shtml.

United Nations (2013) *Millennium Development Goals*. Retrieved 09 October 2013 from the World Wide Web: http://www.un.org/millenniumgoals/bkgd.shtml.

USGBC (2011) *A local government guide: to LEED for neighborhood development. U.S. Green Building Council*. Retrieved 19 October, 2013 from the World Wide Web: http://www.usgbc.org/resources/local-government-guide-leed-neighborhood-development.

USGBC (2013) *LEED*. Retrieved 19 October, 2013 from the World Wide Web: http://www.usgbc.org/leed.

van den Bergh, J.C.J.M. (1996) *Ecological Economics and Sustainable Development: Theory, Methods and Applications*. UK: Edward Elgar Publishing Limited.

Venkatachalam, L. (2007) Environmental economics and ecological economics: Where they can converge?. *Ecological Economics*, 61, 550-558.

Vietnam Green Building Council (2013) *What is LOTUS?*. Retrieved: 19 October 2013 from the World Wide Web: http://www.vgbc.org.vn/en/lotus/lotus-vn-rating-tool.

Wallhagen, M. and Glaumann, M. (2011) Design consequences of differences in building assessment tools: a case study. *Building Research and Information*, 39 (1), 16-33.

Walpole, S. (1996) Land quality as an input to production. *Economic analysis and policy*, 26 (2), 185-207.

Walton, J. S., El-Haram, M., Castillo, N. H., Horner, R. M. W., Price, A. D. F. and Hardcastle, C. (2005) Integrated assessment of urban sustainability. *Proceedings of the ICE - Engineering Sustainability*, 158 (2), 57 –65.

WCED (1987) *Our common future: Report of the World Commission on Environment and Development.* UN documents. Retrieved: 19 October 2013 from the World Wide Web: http://www.un-documents.net/ocf-02.htm

Withanage, H. (1998) *Impacts of Large Dams – The Sri Lankan Experience*. Retrieved 07 November 2011, from the World Wide Web: http://www.internationalrivers.org/files/SriLankaDocuments3.pdf.

Wong, A. (2010) Sustainability of infrastructure projects in Hong Kong: an evaluation of environmental impacts from the perspectives of embodied energy and CO2 emission. Paper presented at the *Infrastructure solutions for tomorrow HKIE Civil Division Conference*, Kowloon, Hong Kong.

World Bank (2001) *What is Sustainable Development*. Retrieved 07 November 2011, from the World Wide Web: http://www.worldbank.org/depweb/english/sd.html.

World Bank (2011) *World Development Indicators 2011*. Washington, D. C.: World Bank.

World Bank (2012a) *Millennium Development Goals*. Retrieved 05 December, 2012 from the World Wide Web: http://www.worldbank.org/mdgs.

World Bank (2012b) *World Bank Group Infrastructure Action Plan South Asia Region*. Retrieved 04 October, 2013 from the World Wide Web: http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTINFRA/0,,contentMDK:23136173~menuPK:8497173~pagePK:64168445~piPK:64168309~theSitePK:8430730,00.html.

World Bank (2013a) *Infrastructure*. Retrieved 04 October, 2013 from the World Wide Web: www.worldbank.org/infrastructure.

World Bank (2013b) *Sri Lanka Overview*. Retrieved 16 October, 2013 from the World Wide Web: http://www.worldbank.org/en/country/srilanka/overview.

WWF (2013) *Infrastructure - Overview, World Wildlife Fund*. Retrieved 13 October, 2013 from the World Wide Web: http://worldwildlife.org/threats/infrastructure.

Yan, H., Shen, Q., Fan, L. C. H., Wang, Y. and Zhang, L. (2010) Greenhouse gas emissions in building construction: A case study of One Peking in Hong Kong. *Building and Environment*, 45, 949-955.

Yin, R. K. (2003) *Case study research design and methods* (3rd ed.). Thousand Oaks: Sage publications.

Young, J. T. (1991) Is the Entropy Law Relevant to the Economics of Natural Resource Scarcity?. *Journal of Environmental Economics and Management*, 21, 169-179.

Young, J. W. S. (1997) A Framework for the Ultimate Environmental Index – Putting Atmospheric Change into Context with Sustainability. *Environmental Monitoring and Assessment*, 46, 135–149.

Young, M. and Vilhauer, R. (2003) *Sri Lanka wind farm analysis and site selection assistance (Subcontract report).* Colorado: National Renewable Energy Laboratory.

Your Home (2007) *A step by step guide to buying a new home*. Sydney: Investa property group.

Your Home (2013) *Buyer's Guide* - *Choosing your new home*. Retrieved: 16 October 2013, from the World Wide Web: http://www.yourhome.gov.au/.

Zofnass Program for Sustainable Infrastructure (2011) Harvard University Graduate School of Design. Retrieved: 28 October 2011, from the World Wide Web: http://www.gsd.harvard.edu/research/research_centers/zofnass/index.html.

Zubair, L. (2001) EIA procedure: Challenges for environmental impact assessment in Sri Lanka. *Environmental Impact Assessment Review*, 21, 469–478.

Appenix-1: Questionnaire Survey

A Framework for Environmental Assessment Schemes for Infrastructure Projects in Sri Lanka

Date:

Dear Sir/ Madam,

I Thilini Jayawickrama, a PhD candidate in National University of Singapore conduct my research on “A Framework for Environmental Assessment Schemes for Infrastructure Projects” under the supervision of Professor George Ofori.

The study aims to develop a theoretical base for Environmental Assessment Schemes and the questionnaire survey is carried out to seek the expert opinion on the importance of addressing a list of environmental impacts related to Infrastructure Projects in Sri Lanka. Some factors are environmental problems whereas some factors are positive impacts. You are required to rank the severity/importance factors to achieve environmental sustainability of infrastructure projects in Sri Lanka.

I am inviting you to participate in this study by completing the attached questionnaire. Please consider the regional as well as global impacts of listed factors. It will require approximately 25 minutes completing the questionnaire.

Responses will only be reported in aggregated form and the privacy of your responses will be guaranteed.

Please try to answer all the questions according to the given instructions. Please note that the factors are repeated in the questionnaire due to the pair wise comparison. It uses a special nine point scale and please read the examples given in the questionnaire which illustrate the ranking method.

If you require additional information or have questions, please contact me at the contact details stated below.

Thank you for your consideration. Your help is greatly appreciated.

Sincerely,

Thilini Jayawickrama

Department of Builiding
School of Design and Environment
National University of Singapore
4, Architecture Drive
Singapore 117566

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Questionnaire survey - Environmental Assessment of Infrastructure Projects

Section A: Respondent details

1. NAME ....
2. ADDRESS ....
3. EMAIL .... TEL. NO. ....
4. Please select an appropriate group from below that you are likely to be associated with

EIA expert	☐	Environmental Economist	☐	Others (please specify)	☐
Environmentalist	☐	Environmental Manager	☐	....	

5. Years of experience ----------------------------
6. Types of projects involved with environmental background --
7. Nature of works carried out --
8. Highest academic qualification achieved PhD/ DSc/ MSc/ BSc/ Dip/ Other (please specify) ------------- in ---

Section B: Introduction of pair wise scale

The 9 - point scale (to be used in every paired comparison)	
Score	**Definition**
1	Both factors are Equally Important/severe
3	Moderately Important/severe
5	Strongly important/ severe
7	Very strongly important/severe
9	Extremely Important/severe

Example:

1 Compare the severity of environmental problems due to **Land Use (ES1)** in Sri Lankan Infrastructure projects with other factors in the right hand side column.

Problems due to Land Use (ES1)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Usage of materials (ES2)
	Both problems are equally severe																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Usage of non-renewable energy sources (ES3)
	ES3 is extremely severe compared to ES1																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste disposal (ES4)
	ES1 is strongly severe compared to ES4																	

Section C: Pair wise comparison of factors with respect to achieving environmental sustainability in infrastructure projects - Sri Lanka

1 Compare the severity of environmental problems due to **Land Use (ES1)** for Sri Lankan Infrastructure projects with other factors in the right handside column.

increasing severity of problems due to Land Use (ES1) ← → increasing severity of problems due to other factors in right handside column

Problems due to Land Use (ES1)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Usage of materials (ES2)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Usage of non-renewable energy sources (ES3)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste disposal (ES4)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Less attention on environmental issues due to Poverty (ES7)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental issues due to corruption (ES8)

2 Compare the importance of **Minimizing Land use (ES1)** with other factors in the right hand side column for achieving environmental sustainability of Sri Lankan infrastructure projects.

increasing importance of Minimizing Land Use (ES2) ← → increasing importance of other factors in right handside column

Minimize Land Use (ES2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Invest in natural capital (ES5)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Conserve Biodiversity (ES6)

3 Compare the severity of different problems of Land use (ES1) in Sri Lankan infrastructure projects, which threat to environmental sustainability.

increasing severity of ES1a ← → increasing severity of ES1b

Excess usage of land areas (ES1a)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Damages to land composition (ES1b)

4 Compare the severity of environmental problems due to **Usage of materials (ES2)** for Sri Lankan Infrastructure projects with other factors in the right handside column.

increasing severity of problems due to Usage of Materials (ES2) ← → increasing severity of problems due to other factors in right handside column

Problems due to Usage of materials (ES2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Usage of non-renewable energy sources (ES3)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste disposal (ES4)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Less attention on environmental issues due to Poverty (ES7)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental issues due to corruption (ES8)

5 Compare the importance of **Minimizing Materials Usage (ES2)** with other factors in the right hand side column for achieving environmental sustainability of Sri Lankan infrastructure projects.

increasing importance of Minimizing Materials Usage (ES2) ← → increasing importance of other factors in right handside column

Minimize Usage of Materials (ES2)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Invest in natural capital (ES5)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Conserve Biodiversity (ES6)

6 Compare the severity of different problems of Usage of Materials (ES2) in Sri Lankan infrastructure projects, which threat to environmental sustainability.

increasing severity of ES2a ← → increasing severity of other problems

Excess usage of materials in terms of quantity (ES2a)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Damages during extraction (ES2b)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Damages due to harmful types (ES2c)

increasing severity of ES2b ← → increasing severity of other problems

Damages during extraction (ES2b)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Damages due to harmful types (ES2c)

7 Compare the severity of environmental problems due to **Usage of Non-Renewable Energy Sources (ES3)** for Sri Lankan Infrastructure projects with other factors in the right handside column.

increasing severity of problems due to Usage of NRE Sources (ES3) ← → increasing severity of problems due to other factors in right handside column

Problems due to Usage of non-renewable energy sources (ES3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Waste disposal (ES4)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Less attention on environmental issues due to Poverty (ES7)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental issues due to corruption (ES8)

8 Compare the importance of **Minimizing Usage of Non-Renewable Energy Sources (ES3)** with other factors in the right hand side column for achieving environmental sustainability of Sri Lankan infrastructure projects.

increasing importance of Minimizing Usage of NRE Sources (ES3) ← → increasing importance of other factors in right handside column

Minimize Usage of non-renewable energy sources (ES3)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Invest in natural capital (ES5)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Conserve Biodiversity (ES6)

9 Compare the severity of different problems of Usage of Non-renewable energy sources (ES3) in Sri Lankan infrastructure projects, which threat to environmental sustainability.

increasing severity of ES3a ← → increasing severity of other problems

Excess usage of Non-renewable energy sources in terms of quantity (ES3a)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Damages during extraction (ES3b)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Damages due to harmful types (ES3c)

increasing severity of ES2b ← → increasing severity of other problems

Damages during extraction (ES3b)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Damages due to harmful types (ES3c)

10 Compare the severity of environmental problems due to **Waste disposal (ES4)** in Sri Lankan Infrastructure projects with other factors in the right handside column.

increasing severity of problems due to Waste disposal (ES4) ← → increasing severity of problems due to other factors in right handside column

Problems due to Waste disposal (ES4)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Less attention on environmental issues due to Poverty (ES7)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental issues due to corruption (ES8)

11 Compare the importance of **Minimizing Waste Disposal (ES4)** with other factors in the right hand side column for achieving environmental sustainability of Sri Lankan infrastructure projects.

increasing importance of Minimizing Waste Disposal (ES4) ← → increasing importance of other factors in right handside column

Minimize Waste disposal (ES4)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Invest in natural capital (ES5)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Conserve Biodiversity (ES6)

12 Compare the severity of different problems of Waste disposal (ES4) in Sri Lankan infrastructure projects, which threat to environmental sustainability.

increasing severity of ES4a ← → increasing severity of other problems

Excess quantity of waste disposal (ES4a)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Damages due to bad quality of waste (ES4b)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Due to location of waste disposed of (ES4c)

increasing severity of ES4b ← → increasing severity of other problems

Damages due to bad quality of waste (ES4b)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Due to location of waste disposed of (ES4c)

13 Compare the importance of **Investing in Natural Capital (ES5)** with other factors in the right hand side column for achieving environmental sustainability of Sri Lankan infrastructure projects.

increasing importance of Investing in Natural Capital (ES5) ← → increasing importance of other factors in right handside column

Invest in natural capital (ES5)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Conserve Biodiversity (ES6)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eradicate Poverty to increase attention on environment (ES7)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Avoid environmental issues due to corruption (ES8)

14 Compare the importance of different aspects of investing in natural capital (ES5) under Sri Lankan infrastructure projects to attain environmental sustainability.

increasing importance of ES5a ← → increasing importance of ES5b

To maintain natural capital stock (ES5a)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	To enhance natural capital stock (ES5b)

15 Compare the importance of **Conserving Biodiversity (ES6)** with other factors in the right hand side column for achieving environmental sustainability of Sri Lankan infrastructure projects.

increasing importance of Investing in Natural Capital (ES5) ← → increasing importance of other factors in right handside column

Conserve Biodiversity (ES6)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eradicate Poverty to increase attention on environment (ES7)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Avoid environmental issues due to corruption (ES8)

16 Compare the severity of environmental problems due to **Less attention on environmental issues due to Poverty (ES7)** for Sri Lankan Infrastructure projects with other factors in the right handside column.

increasing severity of problems due to Waste disposal (ES4) ← → increasing severity of problems due to other factors in right handside column

Problems due to Less attention on environmental issues due to Poverty (ES7)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental issues due to corruption (ES8)

Thank you for your kind co-operation

Appendix 2: Chart Used For Creating the Hierarchical Structure for AHP Analysis – Application to SHP Sector

Please tick (√) in relevant boxes.
This chart provides a list of issues identified in SHP projects. Please select the relevant ES factors for each issue and tick in relevant boxes. Each ES factor and sub-factors are explained below.

ES1	**Minimize Land Use**
ES1a	Minimize land use in terms of land area
ES1b	Minimize damages to land composition
ES2	**Minimize material usage**
ES2a	In terms of quantity
ES2b	In terms of impacts during extraction
ES2c	In terms of impacts during usage
ES3	**Minimize usage of Non-Renewable Energy sources**
ES3a	In terms of quantity
ES3b	In terms of impacts during extraction
ES3c	In terms of impacts during usage
ES4	**Minimize Waste Disposal**
ES4a	In terms of minimizing the quantity
ES4b	In terms of increasing the quality before disposal
ES4c	Ensure the disposal into a proper Location
ES5	**Invest in natural capital**
ES5a	To maintain natural capital stock
ES5b	To enhance natural capital stock
ES6	**Biodiversity**
ES7	**Contributions to Eradicate Poverty**
ES8	**Compliance with Environmental Laws and Standards**

Project performance	Related ES factor															
	ES1		ES2			ES3			ES4			ES5		ES6	ES7	ES8
	a	b	a	b	c	a	b	c	a	b	c	a	b			
Minimize submerged areas																
Avoiding selection of ecologically valuable sites where possible		√												√		
Minimize land take for	√															
i) Temporary works																
ii) Permanent works																
Minimize the area used for temporary facilities through	√															
i) Incorporating temporary facilities into permanent works																
ii) Developing local facilities as part of the project for continuous use after construction																
Minimizing the felling trees														√		
Compensating by replanting loss tree species																
Preventive measures to reduce soil erosion during construction		√														
Minimize rock blasting activities and including		√														
preventive measures to reduce damages																
Minimizing excavation and adopting		√														
preventive measures to reduce damages																
Avoiding loss of aquatic fauna species														√		
Preserving species if the losses are unavoidable														√		
Avoiding disposing into river											√					
Avoiding disposing into nearby lands carelessly																
Avoiding disposing into nearby lands carelessly											√					

Project performance	Related ES factor															
	ES1		**ES2**			**ES3**			**ES4**			**ES5**		**ES6**	**ES7**	**ES8**
	a	**b**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**			
Minimizing waste disposal									√							
Avoiding waste discharge into the water body											√					
Preserving affected species where possible													√	√		
Preventing illegal logging																√
Preventing animal poaching												√		√		√
Preventive measures to avoid invasive species after construction																
Comply the environmental flow requirement																√
Avoid loss of animals														√		
Clean sand, mud and waste periodically												√				
Forestation in the upper catchment areas													√			
Filed survey revealed that SHPs using closed systems of oily liquid flows inside the machineries and no impact on water quality																
Preventive measures to reduce oil leakages during emergency breakdown											√					
To consider the cumulative impacts, the availability of other nearby SHPs should be considered and this requires a master plan for SHPs regulated with the																
Employment opportunities for locals															√	
Forestation in the declared reservation area													√	√		
Develop local facilities as part of the project for continuous usage after construction															√	
Community services carried out by SHP project owners															√	

APPENDIX-3: QUESTIONNAIRE SURVEY - SHP SECTOR

Questionnaire survey
Environmental Sustainability in Small Hydropower (SHP) Projects - Sri Lanka

Section A: Respondent details

Q1. NAME --
Q2. ADDRESS --
Q3. EMAIL --
Q4. DATE --

Section B: Instructions to complete the questionnaire

Please circle a number in 9-point scale to indicate the relative importance of factors (see example below).

Example:

1 Compare the importance of factors 'A' and 'B' for achieving a given objective.

increasing importance of left hand side factors ← → increasing importance of right hand side factors

Factor 'A'	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Factor 'B'
Factor 'A'	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	**9**	Factor 'B'
Factor 'A'	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Factor 'B'
Factor 'A'	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor 'B'

Ranking '1' means, both factors are equally important to achieve the given objective.

Ranking '9' on the right hand side of the scale means , compared to Factor 'A', Factor 'B' is extremely important to achieve the given objective.

Ranking '3' on the left hand side means, Factor 'A' is moderately important than Factor 'B' to achieve the given objective.

Section C: Pair wise comparison of factors with respect to achieving environmental sustainability in SHP projects in Sri Lanka

1 Compare the importance of addressing different impacts of SHP projects listed below, in order to **minimize Land Use (in terms of area).**

	increasing importance of left hand side factors ⟵																increasing importance of right hand side factors ⟶
Minimizing submerged area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimize area utilize for other project components

1.1 Compare the different types of land uses for other project components

Minimize land use for temporary facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimize land use for permanent structures

1.1.1 Compare the different ways to **minimize land take for temporary facilities**

Design to incorporate temporary facilities into permanent works	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Improve and use existing facilities instead of utilizing land for new facilities

2 Compare the importance of addressing different impacts of SHP projects listed below, in order to **Minimize damages to land composition.**

	increasing importance of left hand side factors ⟵																increasing importance of right hand side factors ⟶
Avoid selection of ecologically valuable sites	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimize damages to the selected site areas

2.1 Compare the importance of minimizing impacts listed below that **damaging land composition of selected sites.**

Avoid soil erosion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimize rock blasting
Minimize rock blasting	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimize excavation
Avoid soil erosion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimize excavation

3 Compare the importance of **Minimizing the usage of different types of materials** listed below in SHP projects.

	increasing importance of left hand side factors ⟵																increasing importance of right hand side factors ⟶
Timber usage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Aggregate usage
Aggregate usage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water usage
Water usage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Usage of other construction materials
Timber usage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water usage
Aggregate usage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Usage of other construction materials
Timber usage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Usage of other construction materials

3.1 Compare the importance of different strategies **minimizing the usage of timber** in SHP projects.

Reuse timber within or from outside the project	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reduce the requirement of timber usage

3.2 Compare the importance of different strategies **minimizing the usage of aggregates** in SHP projects.

Reuse aggregates within or from outside the project	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reduce the requirement of aggregates usage

3.3 Compare the importance of different sources to obtain timber for SHP projects in order to **minimize the damages during extraction**.

Obtain timber from sustainable sources	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Obtain aggregates from sustainable sources

4 Compare the importance of addressing different impacts of SHP listed below, in order to **minimize usage of Non-renewable Energy Sources (In terms of quantity)**.

increasing importance of left hand side factors ⟵ ⟶ increasing importance of right hand side factors

Minimize fuel usage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimize electricity usage

4.1 Compare the importance of addressing different aspects of **fuel usage** of SHP listed below, in order to **minimize its usage.**

Fuel for transportation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Fuel for construction plant and machineries

5 Compare the importance of different strategies to **minimize waste disposal (in terms of quantity)** in SHP projects as listed below.

increasing importance of left hand side factors ⟵ ⟶ increasing importance of right hand side factors

Reduce construction waste	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reuse construction waste

5.1 Compare the importance of addressing different impacts of SHP projects listed below, in order to ensure that **wastes are disposed of into a proper Location**.

increasing importance of left hand side factors ⟵ ⟶ increasing importance of right hand side factors

Avoid waste adding to the river	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Avoid waste disposing of into nearby lands
Avoid waste disposing of into nearby lands	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Avoid oil leakages into the river during emergency situations
Avoid waste adding to the river	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Avoid oil leakages into the river during emergency situations

6 Compare the importance of addressing different impacts of SHP projects listed below, which amount to be an **investment in natural capital to maintain its stocks**.

increasing importance of left hand side factors ⟵ ⟶ increasing importance of right hand side factors

Clear away sand and mud in the pond, periodically	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Measures to avoid spreading of invasive species in the affected areas

7 Compare the importance of addressing different impacts of SHP listed below, which amount to be an **investment in natural capital to enhance its stocks**.

	increasing importance of left hand side factors ⟵		increasing importance of right hand side factors ⟶	
Plantation in the surrounding areas	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Preserve affected species

8 Compare the importance of taking different actions listed below in order to Conserve Biodiversity in SHP.

	increasing importance of left hand side factors ⟵		increasing importance of right hand side factors ⟶	
Avoid loss of species	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Minimize loss of species
Minimize loss of species	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Compensating affected species
Compensating affected species	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Enhancing species
Enhancing species	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Prevent invasive species
Avoid loss of species	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Compensating affected species
Minimize loss of species	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Enhancing species
Compensating affected species	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Prevent invasive species
Avoid loss of species	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Enhancing species
Minimize loss of species	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Prevent invasive species
Avoid loss of species	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Prevent invasive species

9 Compare the importance of addressing different impacts of SHP projects listed below, in order to **contribute Eradicating Poverty** as part of the project.

	increasing importance of left hand side factors ⟵		increasing importance of right hand side factors ⟶	
Provide employment opportunities	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Contributing to community services

10 Compare the importance of addressing different impacts of SHP projects listed below, under the compliance with environmental laws and standards

	increasing importance of left hand side factors ⟵		increasing importance of right hand side factors ⟶	
Illegal activities	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Non-compliance with environmental standards

10.1 Compare importance of avoiding different illegal activities listed below in SHP projects.

Animal poaching	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	Illegal logging

Thank you for your kind co-operation

APPENDIX-4: CALCULATION PROCESS FOR AHP ANALYSIS

	ES1	ES2	ES3	ES4	ES5	ES6	ES7	ES8
ES1	**1.00**	1.05	0.50	0.49	0.90	0.40	1.23	1.25
ES2	0.95	**1.00**	0.58	0.67	1.05	0.53	1.48	1.31
ES3	2.01	1.72	**1.00**	0.90	1.67	0.88	2.16	2.07
ES4	2.06	1.50	1.12	**1.00**	1.56	1.04	3.05	2.53
ES5	1.11	0.96	0.60	0.64	**1.00**	0.61	1.19	1.10
ES6	2.50	1.87	1.14	0.96	1.64	**1.00**	2.43	2.45
ES7	0.81	0.67	0.46	0.33	0.84	0.41	**1.00**	0.96
ES8	0.80	0.76	0.48	0.40	0.91	0.41	1.05	**1.00**

SQUARING THE MATRIX TO CALCULATE FIRST EIGEN VECTOR

$$\begin{bmatrix} 1.00 & 1.05 & 0.50 & 0.49 & 0.90 & 0.40 & 1.23 & 1.25 \\ 0.95 & 1.00 & 0.58 & 0.67 & 1.05 & 0.53 & 1.48 & 1.31 \\ 2.01 & 1.72 & 1.00 & 0.90 & 1.67 & 0.88 & 2.16 & 2.07 \\ 2.06 & 1.50 & 1.12 & 1.00 & 1.56 & 1.04 & 3.05 & 2.53 \\ 1.11 & 0.96 & 0.60 & 0.64 & 1.00 & 0.61 & 1.19 & 1.10 \\ 2.50 & 1.87 & 1.14 & 0.96 & 1.64 & 1.00 & 2.43 & 2.45 \\ 0.81 & 0.67 & 0.46 & 0.33 & 0.84 & 0.41 & 1.00 & 0.96 \\ 0.80 & 0.76 & 0.48 & 0.40 & 0.91 & 0.41 & 1.05 & 1.00 \end{bmatrix}$$

$$\begin{bmatrix} 1.00 & 1.05 & 0.50 & 0.49 & 0.90 & 0.40 & 1.23 & 1.25 \\ 0.95 & 1.00 & 0.58 & 0.67 & 1.05 & 0.53 & 1.48 & 1.31 \\ 2.01 & 1.72 & 1.00 & 0.90 & 1.67 & 0.88 & 2.16 & 2.07 \\ 2.06 & 1.50 & 1.12 & 1.00 & 1.56 & 1.04 & 3.05 & 2.53 \\ 1.11 & 0.96 & 0.60 & 0.64 & 1.00 & 0.61 & 1.19 & 1.10 \\ 2.50 & 1.87 & 1.14 & 0.96 & 1.64 & 1.00 & 2.43 & 2.45 \\ 0.81 & 0.67 & 0.46 & 0.33 & 0.84 & 0.41 & 1.00 & 0.96 \\ 0.80 & 0.76 & 0.48 & 0.40 & 0.91 & 0.41 & 1.05 & 1.00 \end{bmatrix}$$

									Normalized Eigen Vector
8.00	7.07	4.31	3.98	7.32	3.87	9.92	9.28	53.74	0.092
9.20	8.00	4.94	4.51	8.28	4.44	11.34	10.58	61.30	0.104
14.97	13.17	8.00	7.36	13.50	7.17	18.36	17.23	99.76	0.170
16.62	14.49	8.88	8.00	14.98	7.92	20.28	19.08	110.26	0.188
9.03	7.85	4.80	4.41	8.00	4.31	11.04	10.33	59.75	0.102
16.81	14.83	8.97	8.22	15.16	8.00	20.61	19.38	111.98	0.191
6.60	5.79	3.52	3.23	5.95	3.16	8.00	7.53	43.80	0.075
6.99	6.13	3.74	3.44	6.31	3.37	8.53	8.00	46.52	0.079
								587.10	1.000

SQUARING THE RESULTED MATRIX FOR THE SECOND ORDER

$$\begin{bmatrix} 8.00 & 7.07 & 4.31 & 3.98 & 7.32 & 3.87 & 9.92 & 9.28 \\ 9.20 & 8.00 & 4.94 & 4.51 & 8.28 & 4.44 & 11.34 & 10.58 \\ 14.97 & 13.17 & 8.00 & 7.36 & 13.50 & 7.17 & 18.36 & 17.23 \\ 16.62 & 14.49 & 8.88 & 8.00 & 14.98 & 7.92 & 20.28 & 19.08 \\ 9.03 & 7.85 & 4.80 & 4.41 & 8.00 & 4.31 & 11.04 & 10.33 \\ 16.81 & 14.83 & 8.97 & 8.22 & 15.16 & 8.00 & 20.61 & 19.38 \\ 6.60 & 5.79 & 3.52 & 3.23 & 5.95 & 3.16 & 8.00 & 7.53 \\ 6.99 & 6.13 & 3.74 & 3.44 & 6.31 & 3.37 & 8.53 & 8.00 \end{bmatrix}$$

$$\begin{bmatrix} 8.00 & 7.07 & 4.31 & 3.98 & 7.32 & 3.87 & 9.92 & 9.28 \\ 9.20 & 8.00 & 4.94 & 4.51 & 8.28 & 4.44 & 11.34 & 10.58 \\ 14.97 & 13.17 & 8.00 & 7.36 & 13.50 & 7.17 & 18.36 & 17.23 \\ 16.62 & 14.49 & 8.88 & 8.00 & 14.98 & 7.92 & 20.28 & 19.08 \\ 9.03 & 7.85 & 4.80 & 4.41 & 8.00 & 4.31 & 11.04 & 10.33 \\ 16.81 & 14.83 & 8.97 & 8.22 & 15.16 & 8.00 & 20.61 & 19.38 \\ 6.60 & 5.79 & 3.52 & 3.23 & 5.95 & 3.16 & 8.00 & 7.53 \\ 6.99 & 6.13 & 3.74 & 3.44 & 6.31 & 3.37 & 8.53 & 8.00 \end{bmatrix}$$

									Normalized Eigen Vector
521.18	456.64	278.63	255.33	469.66	249.79	638.32	598.68	3468.22	0.092
594.47	520.88	317.81	291.24	535.72	284.92	728.09	682.88	3956.02	0.104
967.22	847.46	517.09	473.86	871.63	463.59	1184.63	1111.07	6436.55	0.170
1068.00	935.78	570.97	523.25	962.45	511.90	1308.08	1226.84	7107.27	0.188
579.22	507.51	309.66	283.77	521.99	277.62	709.42	665.37	3854.56	0.102
1084.90	950.56	580.01	531.52	977.68	520.00	1328.77	1246.24	7219.67	0.191
424.99	372.37	227.21	208.21	382.99	203.70	520.54	488.21	2828.22	0.075
451.44	395.55	241.35	221.17	406.83	216.37	552.92	518.59	3004.22	0.079
								37874.74	1.000

COMPUTE THE DIFFERENCE OF TWO EIGENVECTOR CALCULATIONS

0.09	-	0.09	=	0.00
0.10	-	0.10	=	0.00
0.17	-	0.17	=	0.00
0.19	-	0.19	=	0.00
0.10	-	0.10	=	0.00
0.19	-	0.19	=	0.00
0.07	-	0.07	=	0.00
0.08	-	0.08	=	0.00

NO DIFFERENCE AND HENCE, CONSIDER NORMALIZED WEIGHTS AS FINAL VECTOR PRIORITIES

ES1	0.092
ES2	0.104
ES3	0.170
ES4	0.188
ES5	0.102
ES6	0.191
ES7	0.075
ES8	0.079

CALCULATIONS FOR CONSISTENCY

CALCULATING SUM OF THE COLUMNS

1.00	1.05	0.50	0.49	0.90	0.40	1.23	1.25
0.95	1.00	0.58	0.67	1.05	0.53	1.48	1.31
2.01	1.72	1.00	0.90	1.67	0.88	2.16	2.07
2.06	1.50	1.12	1.00	1.56	1.04	3.05	2.53
1.11	0.96	0.60	0.64	1.00	0.61	1.19	1.10
2.50	1.87	1.14	0.96	1.64	1.00	2.43	2.45
0.81	0.67	0.46	0.33	0.84	0.41	1.00	0.96
0.80	0.76	0.48	0.40	0.91	0.41	1.05	1.00
11.25	**9.53**	**5.88**	**5.38**	**9.57**	**5.28**	**13.59**	**12.66**

DIVIDE THE MATRIX BY EACH COLUMN SUM AND CALCULATE SUM OF ROWS

									AVERAGE SUM
0.09	0.11	0.08	0.09	0.09	0.08	0.09	0.10	**0.73**	0.09
0.08	0.10	0.10	0.12	0.11	0.10	0.11	0.10	**0.84**	0.10
0.18	0.18	0.17	0.17	0.17	0.17	0.16	0.16	**1.36**	0.17
0.18	0.16	0.19	0.19	0.16	0.20	0.22	0.20	**1.50**	0.19
0.10	0.10	0.10	0.12	0.10	0.12	0.09	0.09	**0.81**	0.10
0.22	0.20	0.19	0.18	0.17	0.19	0.18	0.19	**1.52**	0.19
0.07	0.07	0.08	0.06	0.09	0.08	0.07	0.08	**0.60**	0.07
0.07	0.08	0.08	0.07	0.10	0.08	0.08	0.08	**0.64**	0.08

MULTIPLY THE MATRIX BY EACH AVERAGE ROW SUM

								Aw	λ max
0.09	0.11	0.08	0.09	0.09	0.08	0.09	0.10	0.74	8.03
0.09	0.10	0.10	0.13	0.11	0.10	0.11	0.10	0.84	8.03
0.18	0.18	0.17	0.17	0.17	0.17	0.16	0.16	1.37	8.03
0.19	0.16	0.19	0.19	0.16	0.20	0.23	0.20	1.51	8.04
0.10	0.10	0.10	0.12	0.10	0.12	0.09	0.09	0.82	8.03
0.23	0.20	0.19	0.18	0.17	0.19	0.18	0.19	1.53	8.04
0.07	0.07	0.08	0.06	0.09	0.08	0.07	0.08	0.60	8.03
0.07	0.08	0.08	0.07	0.09	0.08	0.08	0.08	0.64	8.03
								Average λ max	8.03

<u>CALCULATION FOR SUB-FACTORS (ES1)</u>

	ES1a	ES1b
ES1a	**1.000**	0.625
ES1b	1.599	**1.000**

SQUARING THE MATRIX TO CALCULATE FIRST EIGEN VECTOR

$$\begin{vmatrix} 1.00 & 0.63 \\ 1.60 & 1.00 \end{vmatrix}$$

$$\begin{vmatrix} 1.00 & 0.63 \\ 1.60 & 1.00 \end{vmatrix}$$

			Normalized
2.00	1.25	3.25	0.385
3.20	2.00	5.20	0.615
		8.45	

SQUARING THE RESULTED MATRIX FOR THE SECOND ORDER

$$\begin{vmatrix} 2.00 & 1.25 \\ 3.20 & 2.00 \end{vmatrix}$$

$$\begin{vmatrix} 2.00 & 1.25 \\ 3.20 & 2.00 \end{vmatrix}$$

8.00	5.00	13.00	0.385
12.79	8.00	20.79	0.615
		33.80	

NO DIFFERENCE AND HENCE, CONSIDER NORMALIZED WEIGHTS AS FINAL VECTOR PRIORITIES

ES1a	0.385
ES1b	0.615

<u>CALCULATION FOR SUB-FACTORS (ES2)</u>

	ES2a	ES2b	ES2c
ES2a	**1.000**	0.747	0.843
ES2b	1.338	**1.000**	1.292
ES2c	1.187	0.774	**1.000**

SQUARING THE MATRIX TO CALCULATE FIRST EIGEN VECTOR

$$\begin{vmatrix} 1.000 & 0.747 & 0.843 \\ 1.338 & 1.000 & 1.292 \\ 1.187 & 0.774 & 1.000 \end{vmatrix}$$

$$\begin{vmatrix} 1.00 & 0.75 & 0.84 \\ 1.34 & 1.00 & 1.29 \\ 1.19 & 0.77 & 1.00 \end{vmatrix}$$

				Normalized
3.00	2.15	2.65	7.80	0.283
4.21	3.00	3.71	10.92	0.396
3.41	2.43	3.00	8.84	0.321
			27.56	1.000

SQUARING THE RESULTED MATRIX FOR THE SECOND ORDER

$$\begin{vmatrix} 3.00 & 2.15 & 2.65 \\ 4.21 & 3.00 & 3.71 \\ 3.41 & 2.43 & 3.00 \end{vmatrix}$$

$$\begin{vmatrix} 3.00 & 2.15 & 2.65 \\ 4.21 & 3.00 & 3.71 \\ 3.41 & 2.43 & 3.00 \end{vmatrix}$$

				Normalized
27.07	19.33	23.87	70.28	0.283
37.91	27.07	33.43	98.41	0.396
30.71	21.93	27.07	79.71	0.321
			248.40	1.000

NO DIFFERENCE AND HENCE, CONSIDER NORMALIZED WEIGHTS AS FINAL VECTOR PRIORITIES

ES2a	0.283
ES2b	0.396
ES2c	0.321

CALCULATIONS FOR CONSISTENCY

CALCULATING SUM OF THE COLUMNS

1.00	0.75	0.84
1.34	1.00	1.29
1.19	0.77	1.00
3.53	**2.52**	**3.13**

MULTIPLY THE MATRIX BY EACH COLUMN SUM AND CALCULATE SUM OF ROWS

				Average Sum
3.53	1.88	2.64	**8.05**	2.68
4.72	2.52	4.05	**11.29**	3.76
4.18	1.95	3.13	**9.27**	3.09

MULTIPLY THE MATRIX BY EACH AVERAGE ROW SUM

			Aw	λ max
2.68	2.81	2.60	8.10	3.02
3.59	3.76	3.99	11.35	3.02
3.18	2.91	3.09	9.19	2.97
			Average λ max	3.00

CALCULATION FOR SUB-FACTORS (ES3)

	ES3a	ES3b	ES3c
ES3a	**1.000**	1.193	1.388
ES3b	0.839	**1.000**	1.060
ES3c	0.721	0.944	**1.000**

SQUARING THE MATRIX TO CALCULATE FIRST EIGEN VECTOR

$$\begin{vmatrix} 1.00 & 1.19 & 1.39 \\ 0.84 & 1.00 & 1.06 \\ 0.72 & 0.94 & 1.00 \end{vmatrix}$$

$$\begin{vmatrix} 1.00 & 1.19 & 1.39 \\ 0.84 & 1.00 & 1.06 \\ 0.72 & 0.94 & 1.00 \end{vmatrix}$$

				Normalized
3.00	3.69	4.04	10.73	0.391
2.44	3.00	3.28	8.72	0.318
2.23	2.75	3.00	7.98	0.291
			27.44	1.000

SQUARING THE RESULTED MATRIX FOR THE SECOND ORDER

$$\begin{vmatrix} 3.00 & 3.69 & 4.04 \\ 2.44 & 3.00 & 3.28 \\ 2.23 & 2.75 & 3.00 \end{vmatrix}$$

3.00	3.69	4.04
2.44	3.00	3.28
2.23	2.75	3.00

				Normalized
27.03	33.26	36.37	96.66	0.391
21.98	27.03	29.56	78.57	0.318
20.10	24.73	27.03	71.86	0.291
			247.09	1.000

NO DIFFERENCE AND HENCE, CONSIDER NORMALIZED WEIGHTS AS FINAL VECTOR PRIORITIES

ES3a	0.391
ES3b	0.318
ES3c	0.291

CALCULATIONS FOR CONSISTENCY

CALCULATING SUM OF THE COLUMNS

1.00	1.19	1.39
0.84	1.00	1.06
0.72	0.94	1.00
2.56	**3.14**	**3.45**

MULTIPLY THE MATRIX BY EACH COLUMN SUM AND CALCULATE SUM OF ROWS

				Average Sum
2.56	3.74	4.78	**11.08**	3.69
2.15	3.14	3.65	**8.94**	2.98
1.84	2.96	3.45	**8.25**	2.75

MULTIPLY THE MATRIX BY EACH AVERAGE ROW SUM

			Aw	λ max
3.69	3.55	3.82	11.06	2.99
3.10	2.98	2.91	8.99	3.02
2.66	2.81	2.75	8.22	2.99
			Average λ max	3.00

CALCULATION FOR SUB-FACTORS (ES4)

	ES4a	ES4b	ES4c
ES4a	**1.000**	0.650	0.595
ES4b	1.538	**1.000**	1.014
ES4c	1.680	0.986	**1.000**

SQUARING THE MATRIX TO CALCULATE FIRST EIGEN VECTOR

1.00	0.65	0.60
1.54	1.00	1.01
1.68	0.99	1.00

1.00	0.65	0.60
1.54	1.00	1.01
1.68	0.99	1.00

				Normalized
3.00	1.89	1.85	6.74	0.237
4.78	3.00	2.94	10.73	0.378
4.88	3.06	3.00	10.94	0.385
			28.40	1.000

SQUARING THE RESULTED MATRIX FOR THE SECOND ORDER

3.00	1.89	1.85
4.78	3.00	2.94
4.88	3.06	3.00

3.00	1.89	1.85
4.78	3.00	2.94
4.88	3.06	3.00

				Normalized
27.04	16.99	16.65	60.68	0.237
43.05	27.04	26.51	96.60	0.378
43.91	27.58	27.04	98.53	0.385
			255.82	1.000

NO DIFFERENCE AND HENCE, CONSIDER NORMALIZED WEIGHTS AS FINAL VECTOR PRIORITIES

ES3a	0.237
ES3b	0.378
ES3c	0.385

CALCULATIONS FOR CONSISTENCY

CALCULATING SUM OF THE COLUMNS

1.00	0.65	0.60
1.54	1.00	1.01
1.68	0.99	1.00
4.22	**2.64**	**2.61**

MULTIPLY THE MATRIX BY EACH COLUMN SUM AND CALCULATE SUM OF ROWS

				Average Sum
4.22	1.71	1.55	**7.49**	2.50
6.49	2.64	2.65	**11.77**	3.92
7.09	2.60	2.61	**12.30**	4.10

MULTIPLY THE MATRIX BY EACH AVERAGE ROW SUM

			Aw	λ max
2.50	2.55	2.44	7.49	3.00
3.84	3.92	4.16	11.92	3.04
4.19	3.87	4.10	12.16	2.97
		Average λ max		3.00

CALCULATION FOR SUB-FACTORS (ES5)

	ES5a	ES5b
ES5a	**1.000**	1.350
ES5b	0.740	**1.000**

SQUARING THE MATRIX TO CALCULATE FIRST EIGEN VECTOR

$$\begin{vmatrix} 1.00 & 1.35 \\ 0.74 & 1.00 \end{vmatrix}$$

$$\begin{vmatrix} 1.00 & 1.35 \\ 0.74 & 1.00 \end{vmatrix}$$

			Normalized
2.00	2.70	4.70	0.575
1.48	2.00	3.48	0.425
		8.18	

SQUARING THE RESULTED MATRIX FOR THE SECOND ORDER

$$\begin{vmatrix} 2.00 & 2.70 \\ 1.48 & 2.00 \end{vmatrix}$$

$$\begin{vmatrix} 2.00 & 2.70 \\ 1.48 & 2.00 \end{vmatrix}$$

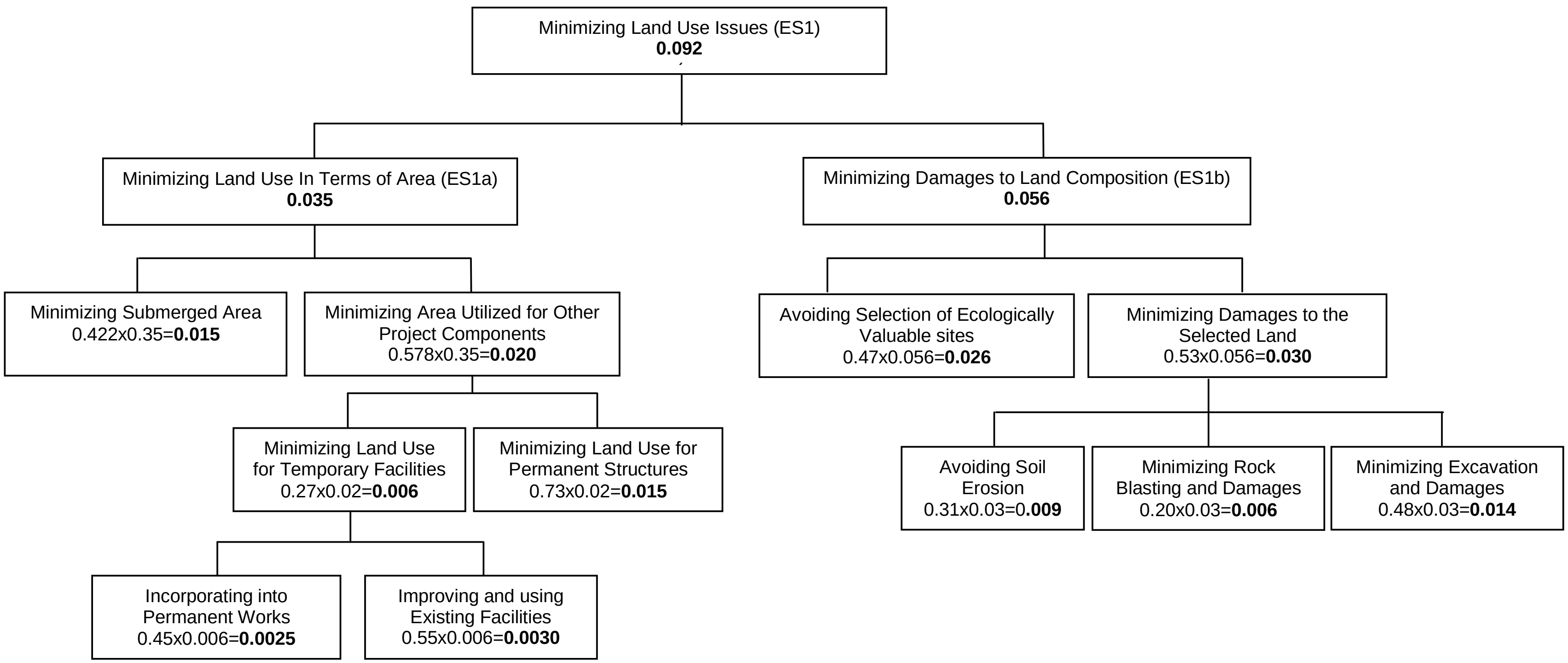
8.00	10.80	18.80	0.575
5.92	8.00	13.92	0.425
		32.73	

NO DIFFERENCE AND HENCE, CONSIDER NORMALIZED WEIGHTS AS FINAL VECTOR PRIORITIES

ES5a	0.575
ES5b	0.425

Appendix 5: Calculation of Final Weightings for Issues Identified In SHP Projects

Issues under Land Use (ES1)



There are no issues of SHP projects to be considered under the sub-factor ES2c and therefore, weightings of ES2 should be redistributed only among sub-factors ES2a and ES2b as follows.

CALCULATION FOR SUB-FACTORS (ES2)

	ES2a	ES2b
ES2a	**1.000**	0.747
ES2b	1.338	**1.000**

SQUARING THE MATRIX TO CALCULATE FIRST EIGEN VECTOR

$$\begin{vmatrix} 1.00 & 0.75 \\ 1.34 & 1.00 \end{vmatrix}$$

$$\begin{vmatrix} 1.00 & 0.75 \\ 1.34 & 1.00 \end{vmatrix}$$

			Normalized
2.00	1.49	3.49	0.428
2.68	2.00	4.68	0.572
		8.17	

SQUARING THE RESULTED MATRIX FOR THE SECOND ORDER

$$\begin{vmatrix} 2.00 & 1.49 \\ 2.68 & 2.00 \end{vmatrix}$$

$$\begin{vmatrix} 2.00 & 1.49 \\ 2.68 & 2.00 \end{vmatrix}$$

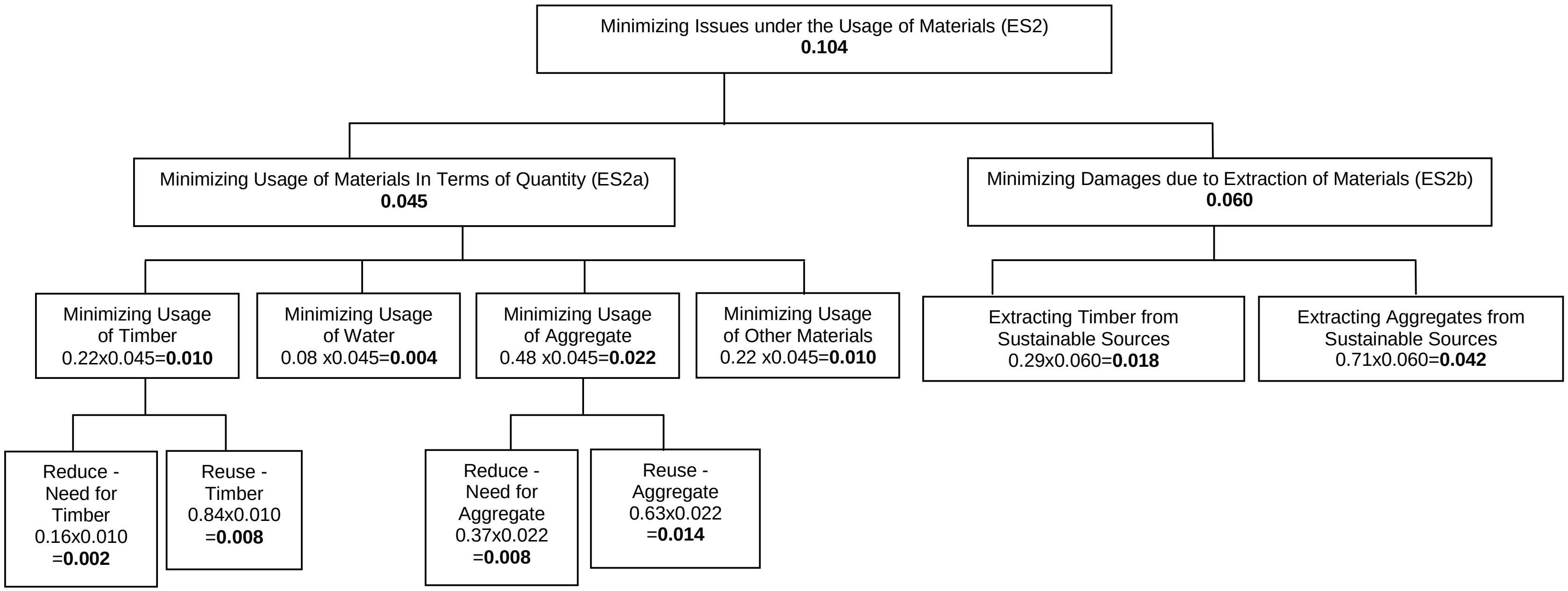
8.00	5.98	13.98	0.428
10.71	8.00	18.71	0.572
		32.68	

NO DIFFERENCE AND HENCE, CONSIDER NORMALIZED WEIGHTS AS FINAL VECTOR PRIORITIES

ES2a	0.428
ES2b	0.572

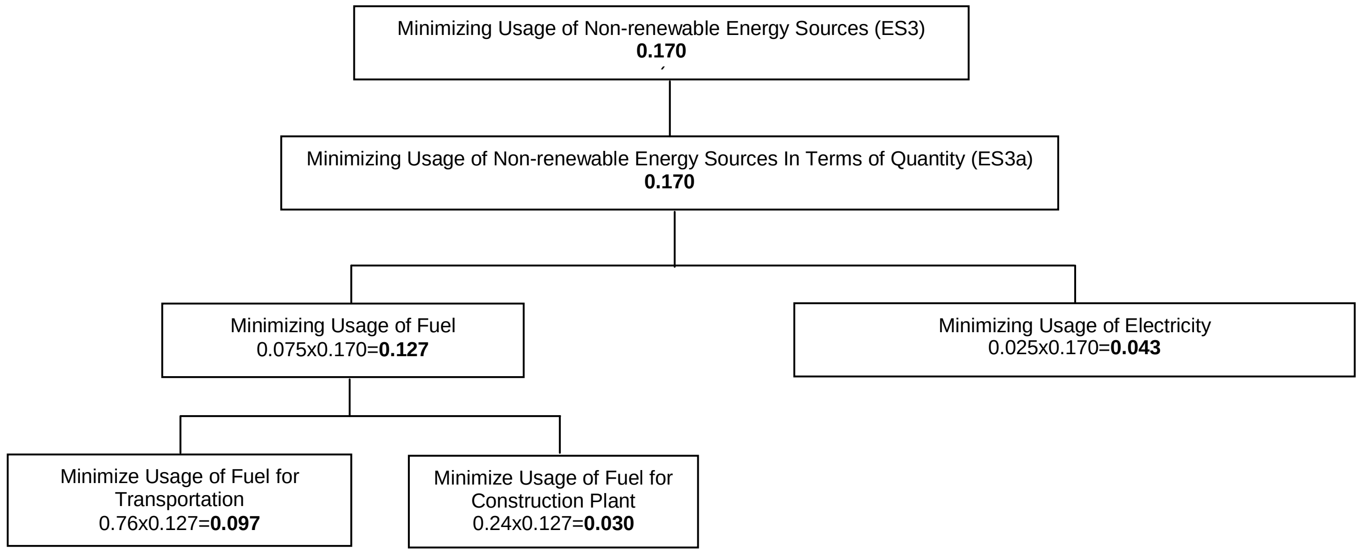
	Qty (ES2a)	Extra. (ES2b)	Normalized weight	ES2 weight	Final weight
Qty (ES2a)	**1.000**	0.747	0.428	0.104	**0.045**
Extra. (ES2b)	1.338	**1.000**	0.572	0.104	**0.060**
			1.000		0.105

Issue under Usage of Materials (ES2)



Issue under Usage of Non-renewable Energy Sources (ES3)

There are no issues of SHP projects to be considered under the sub-factor ES3b and ES3c, and therefore, weighting of ES3 was considered only under the sub-factor ES3a as follows.



There are no issues of SHP projects to be considered under the sub-factor ES4b and therefore, weightings of ES4 should be redistributed only among sub-factors ES4a and ES4c as follows.

CALCULATION FOR SUB-FACTORS (ES4)

	ES4a	ES4c
ES4a	**1.000**	0.595
ES4c	1.680	**1.000**

SQUARING THE MATRIX TO CALCULATE FIRST EIGEN VECTOR

$$\begin{vmatrix} 1.00 & 0.60 \\ 1.68 & 1.00 \end{vmatrix}$$

$$\begin{vmatrix} 1.00 & 0.60 \\ 1.68 & 1.00 \end{vmatrix}$$

			Normalized
2.00	1.19	3.19	0.373
3.36	2.00	5.36	0.627
		8.55	

SQUARING THE RESULTED MATRIX FOR THE SECOND ORDER

$$\begin{vmatrix} 2.00 & 1.19 \\ 3.36 & 2.00 \end{vmatrix}$$

$$\begin{vmatrix} 2.00 & 1.19 \\ 3.36 & 2.00 \end{vmatrix}$$

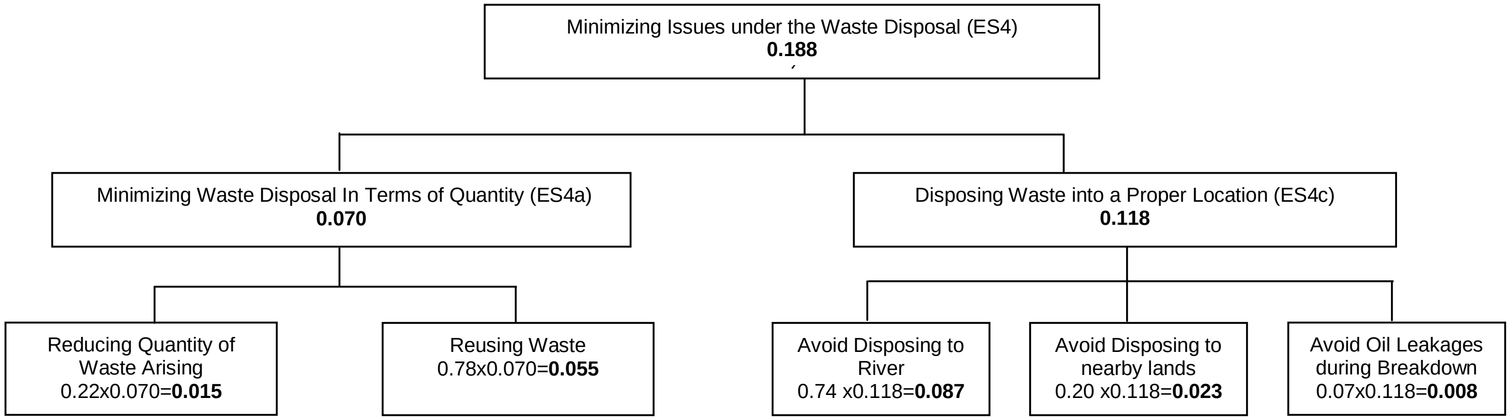
8.00	4.76	12.76	0.373
13.44	8.00	21.44	0.627
		34.20	

NO DIFFERENCE AND HENCE, CONSIDER NORMALIZED WEIGHTS AS FINAL VECTOR PRIORITIES

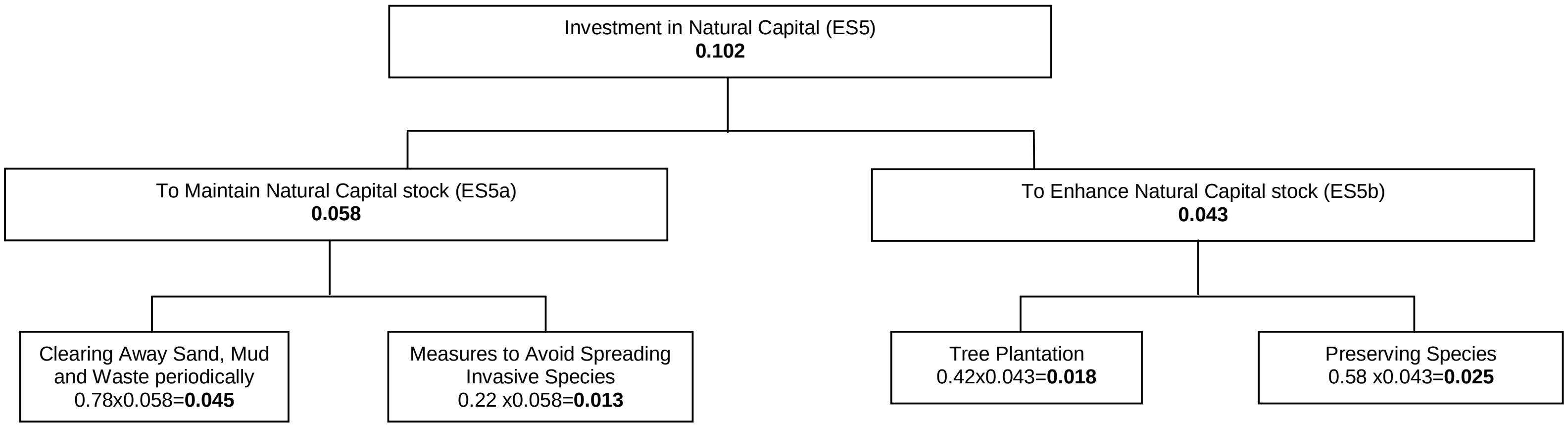
ES4a	0.373
ES4c	0.627

	Qty (ES4a)	Loc. (ES4c)	Normalized weight	ES4 weight	Final weight
Qty (ES4a)	**1.000**	0.595	0.373	0.188	**0.070**
Loc. (ES4c)	1.680	**1.000**	0.627	0.188	**0.118**
			1.000		0.188

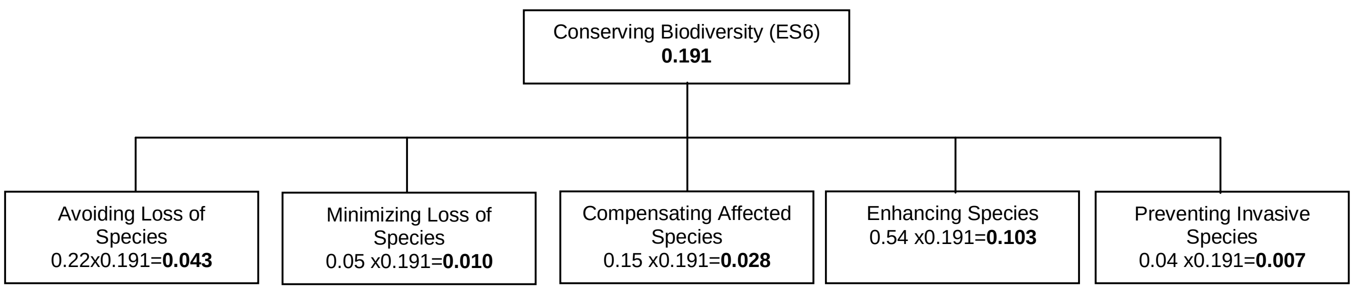
Issue under Waste Disposal (ES4)



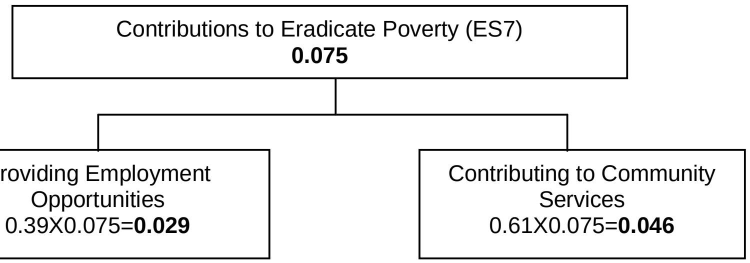
Ways to Invest in Natural Capital (ES5)



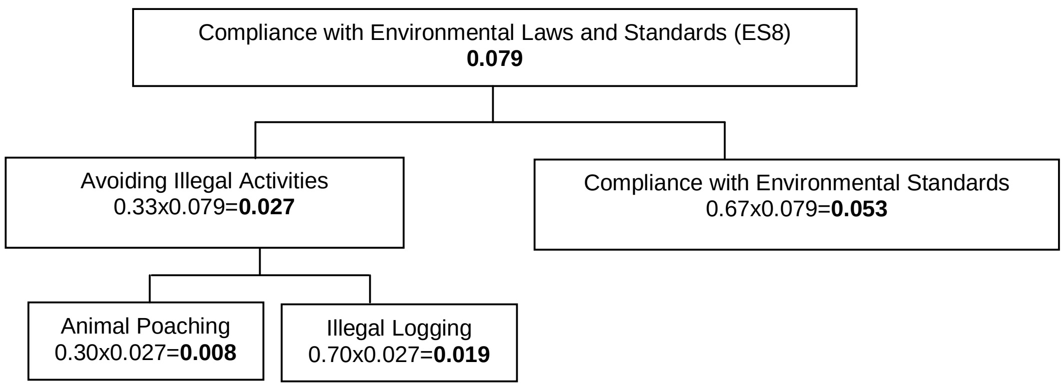
Biodiversity Conservation (ES6)



Contributions to Eradicating Poverty (ES7)



Compliance with Environmental Laws and Standards (ES8)



Appendix 6 – Publications

Jayawickrama, T. S., Ofori, G. and Low, S. P. (2013) Environmental Sustainability: A Framework for Environmental Assessment Schemes. Paper presented at *CIB World Building Congress 2013*, Brisbane, Australia, 5- 9 May.

Jayawickrama, T. S., Ofori, G. and Low, S. P. (2013) A Framework for Environmental Rating Schemes for Infrastructure Projects. In Y. G. Sandanayake and N. G. Fernando (Eds.) *Proceedings of the Second World Construction Symposium* (pp. 1-11). Sri Lanka: Ceylon Institute of Builders.

Jayawickrama, T. S. and Ofori, G. (2014) Environmental assessment of Small Hydropower projects in Sri Lanka. Paper accepted for the presentation at *ASIA 2014 – Fifth International Conference on Water Resources and Renewable Energy Development in Asia*.